1292

Issued January 20, 1911.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 230, PART I.

A. C. TRUE, Director.

REPORT

ON THE

ST. FRANCIS VALLEY DRAINAGE PROJECT IN NORTHEASTERN ARKANSAS.

PART I.—GENERAL REPORT.

BY

ARTHUR E. MORGAN,
Supervising Drainage Engineer.

ASSISTED BY

O. G. BAXTER,
Drainage Engineer.

PREPARED UNDER THE DIRECTION OF

C. G. ELLIOTT,
Chief of Drainage Investigations.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON DRAINAGE.

NOTE.—For those publications to which a price is affixed, application should be made to the Superintendent of Documents, Government Printing Office, Washington, D. C., the officer designated by law to sell government publications. Publications marked with an asterisk (*) are not available for distribution. All other publications may be obtained by addressing the Secretary of Agriculture, Washington, D. C.

BULLETINS.

Bul. 147. Report on Drainage Investigations in 1903. By C. G. Elliott. Pp. 62, pls. 5, figs. 12. Price 10 cents.

Bul. 189. Report on the Drainage of the Eastern Parts of Cass, Traill, Grand Forks, Walsh, and Pembina Counties, North Dakota. By John T. Stewart. Pp. 71, pls. 6, figs. 2. Price 25 cents.

Bul. 198. The Prevention of Injury by Floods in the Neosho Valley, Kansas. By J. O. Wright. Pp. 44, pls. 14, figs. 3. Price 20 cents.

Bul. 217. The Drainage of Irrigated Lands in the San Joaquin Valley, California. By S. Fortier and V. M. Cone. Pp. 58, pls. 2, figs. 9. Price 15 cents.

Bul. 230. Report on the St. Francis Valley Drainage Project in Northeastern Arkansas—Part II. Bench marks. By A. E. Morgan and O. G. Baxter. Pp. 58. (In press.)

Bul. 234. A Report upon the Reclamation of the Overflowed Lands in the Marais des Cygnes Valley, Kansas. By W. J. McEathron, S. H. McCrory, and D. L. Yarnell. (In press.)

FARMERS' BULLETINS.

Bul. 187. Drainage of Farm Lands. By C. G. Elliott. Pp. 38, figs. 19.

Bul. 371. Drainage of Irrigated Lands. By C. F. Brown. Pp. 52, figs. 19.

CIRCULARS.

Circ. 50. Preliminary Plans and Estimates for Drainage of Fresno District, California. By C. G. Elliott. Pp. 9. Price 5 cents.

Circ. 57. Supplemental Report on Drainage in the Fresno District, California. By C. G. Elliott. Pp. 5. Price 5 cents.

Circ. 74. Excavating Machinery Used for Digging Ditches and Building Levees. By J. O. Wright. Pp. 40, figs. 16.

*Circ. 76. The Swamp and Overflowed Lands of the United States. By J. O. Wright. Pp. 23, pl. 1. Price 5 cents.

Circ. 80. A Report upon the Drainage of Agricultural Lands in the Kankakee River Valley, Indiana. By C. G. Elliott. Pp. 23, figs. 3.

Circ. 81. A Report upon the Drainage of the Agricultural Lands of Bolivar County, Mississippi. By W. J. McEathron and S. H. McCrory. Pp. 28, fig. 1. Price 5 cents.

Circ. 86. Preliminary Report on the St. Francis Valley Drainage Project in Northeastern Arkansas. By A. E. Morgan. Pp. 31, figs. 3.

Circ. 88. Organization, Work, and Publications of Drainage Investigations. Pp. 6.

Circ. 103. The Drainage Situation in the Lower Rio Grande Valley, Texas. By L. L. Hidinger. Pp. 36, figs. 3.

SEPARATES.

*Yearbook Extract No. 265. Some Engineering Features of Drainage. By C. G. Elliott. Pp. 231–244, pl. 1, figs. 2. (Reprint from Yearbook, 1902.)

Sep. 9, Bul. 158. Report of Drainage Investigations, 1904. By C. G. Elliott. Pp. 643–743, pls. 4, figs. 52.

*Doc. 799. Report of Irrigation and Drainage Investigations, 1904. By Elwood Mead, Chief. Pp. 425–472, pls. 5, figs. 5. (Reprint from Annual Report of the Office of Experiment Stations for 1904.)

[Continued on page 3 of cover.]

1292 Issued January 20, 1911.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 230, PART I.

A. C. TRUE, Director.

REPORT

ON THE

ST. FRANCIS VALLEY DRAINAGE PROJECT IN NORTHEASTERN ARKANSAS.

PART I.—GENERAL REPORT.

BY

ARTHUR E. MORGAN,

Supervising Drainage Engineer.

ASSISTED BY

O. G. BAXTER,

Drainage Engineer.

PREPARED UNDER THE DIRECTION OF

C. G. ELLIOTT,

Chief of Drainage Investigations.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1911.

OFFICE OF EXPERIMENT STATIONS.

A. C. True, Director.
E. W. Allen, Assistant Director.

DRAINAGE INVESTIGATIONS.

C. G. Elliott, Chief Drainage Engineer and Chief of Drainage Investigations.
A. D. Morehouse, Office Engineer and Acting Chief in absence of the Chief.

ASSISTANT OFFICE ENGINEERS.

R. D. Marsden, H. H. Barrows, N. B. Wade.

DRAFTSMEN.

G. F. Pohlers, H. B. Artley.

DRAINAGE ENGINEERS.

W. J. McEathron, S. H. McCrory, H. A. Kipp, F. F. Shafer, W. W. Weir, O. G. Baxter.

ASSISTANT DRAINAGE ENGINEERS.

G. M. Warren, D. L. Yarnell, J. V. Phillips, L. A. Jones, F. G. Eason, C. W. Okey, J. R. Haswell, W. J. Schlick, A. G. Hall, C. W. Mengel.

DRAINAGE ENGINEERS FOR IRRIGATED LANDS.

D. G. Miller, R. A. Hart, S. W. Cooper, W. A. Kelly, J. C. Carpenter.

ENGINEERS AVAILABLE FOR SPECIAL WORK.

A. E. Morgan, S. M. Woodward, J. F. Stewart, C. F. Brown, L. L. Hidinger.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., July 29, 1910.

Sir: I have the honor to transmit herewith a report, accompanied by five maps and a number of profiles and illustrations, on the St. Francis Valley drainage project in northeastern Arkansas, prepared by members of the force engaged in Drainage Investigations in this Office. A preliminary report on this same project was printed as Circular 86 of the Office of Experiment Stations, but the plan has since been worked out much more in detail and is now presented as a comprehensive treatment of the subject.

Owing to the fact that the project is a large one, involving the reclamation of over a million acres, and as it includes some unusual engineering features, such as the construction of large floodways for carrying the drainage from southeastern Missouri through the district and the construction of inverted siphons for carrying the drainage water of the district beneath these floodways, it was deemed advisable to have the plan passed upon by a board of consulting engineers. This board consisted of Mr. Isham Randolph, consulting engineer, of Chicago; Prof. A. Marston, dean of engineering, Iowa State College, Ames, Iowa; and Mr. S. M. Woodward, professor of hydraulics, Iowa State University, Iowa City, Iowa. The three following railroads, whose lines traverse the district, appreciating the necessity of dealing with the matter as a whole to insure best results, paid for the consultation and also assisted throughout in every way possible: The St. Louis and Southwestern Railway Company, the St. Louis, Iron Mountain and Southern Railway Company, and the St. Louis and San Francisco Railroad Company.

In view of the great interest which attaches to this project and the large number of requests for the report already received, it is desired that the report be made available for general distribution. The report consists of two parts. Part I, General Report, contains the information sought by the greater number of those interested. Part II, Bench Marks, consists of a list of bench marks established throughout the whole district by the drainage survey and which will be of exceeding value to the more limited number of those who will be charged with carrying out the plans either in part or in full. I therefore recommend that the report be printed as Bulletin 230, Parts I and II, of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

230–1

ILLUSTRATIONS.

PLATES.

TEXT FIGURES.

ST. FRANCIS VALLEY DRAINAGE PROJECT IN NORTHEASTERN ARKANSAS—PART I.

INTRODUCTION.[a]

The drainage of the upper part of the St. Francis Valley in Arkansas was first actively advocated by the St. Francis Valley Drainage Association, which was organized in 1904. The value of a comprehensive plan and the necessity of cooperation on the part of the people for the purpose of securing it were presented by that association at several public meetings. In 1906 Mr. S. H. McCrory, drainage engineer of the Office of Experiment Stations, made an examination of the field and reported that while several independent drainage districts had been organized a comprehensive plan for the entire valley would be required before adequate drainage could be secured. This fact becoming apparent to the landowners of that region, a request was made, in the spring of 1908, to the U. S. Department of Agriculture that the Division of Drainage Investigations, of the Office of Experiment Stations, cooperate in making the needed survey and preparing such a plan.

In June, 1908, Mr. C. G. Elliott, Chief of Drainage Investigations, proposed to the people of the upper St. Francis Valley a basis for cooperation, whereby the expense of a survey would be shared equally by the Division of Drainage Investigations and the people of the district. The proposition was accepted by the St. Francis Valley Drainage Investigations Association, which was organized on July 27, for the purpose of cooperating in the survey. Field work was begun in October, 1908, under the direction of Arthur E. Morgan, supervising drainage engineer, and was continued until March, 1909. The field parties were in charge of H. A. Kipp, Lawrence Brett, O. M. Fairley, F. F. Shafer, O. G. Baxter, George R. Boyd, and W. W. Weir. Three to five parties were kept in the field and twenty to forty men were employed. Headquarters were established at Jonesboro, the various parties camping on the work. The entire cost charged against Drainage Investigations for the field work and later for preparing the plans and report was $13,000, and the cost to the St. Francis Valley Drainage Investigation Association was $7,273. About

[a] A brief summary of the plan for drainage proposed in this report is given on pp. 54–56.

$1,570 was spent in the district on account of Drainage Investigations previous to the date when arrangements were made for cooperation. About 1,700 miles of level and transit line were run, at an average cost of $11.37 per mile, including the expense of the office at Jonesboro and all other field charges, but not including the cost of preparing the report in the Washington office. On an average about 1 mile of line was run for every square mile of land in the district. The survey being for drainage purposes, no effort was made to locate precisely land lines or section corners. In preparing the report use was also made of a previous survey by O. M. Fairley and W. W. Weir, covering parts of Mississippi County.

In July, 1909, a preliminary report was issued (Circular 86, Office of Experiment Stations) giving the results of the investigation as they had been worked out up to that time. A complete report is now presented, in which numerous changes have been made, as seemed necessary or desirable, and a more detailed statement of the situation is submitted.

DESCRIPTION OF THE ST. FRANCIS VALLEY.

LOCATION.

The St. Francis Valley is situated in southeastern Missouri and northeastern Arkansas. Beginning about 100 miles south of St. Louis, it extends southerly more than 300 miles to the mouth of the St. Francis River near Helena, Ark. It is bounded by the Mississippi River on the east, and by a low narrow rise of land, known as Crowleys Ridge, on the west. At the north the flat valley ends abruptly at the foothills of the Ozark Mountains. (See map, fig. 1.)

The area considered in this report, including about 1,600 square miles, or more than 1,000,000 acres, extends from the Arkansas-Missouri state line south into Arkansas for about 65 miles. The greatest width, from Crowleys Ridge to the Mississippi River opposite Jonesboro, is about 50 miles. All of Mississippi County, the eastern parts of Craighead and Poinsett, the northeastern part of Cross, and the northern part of Crittenden counties, are included.

The St. Louis-Memphis line of the St. Louis and San Francisco Railroad extends through the length of the district along the Mississippi River, while the Memphis-Kansas City line of the same road passes through the heart of the territory between Memphis, Tenn., and Jonesboro, Ark. A third line of this road will soon be completed from Marked Tree north to the state line, north of Leachville, there connecting with other branches of the system in Missouri. The Iron Mountain and Cotton Belt railroads pass along the west margin; the Iron Mountain Railroad borders it on the south; the Jonesboro, Lake City and Eastern Railroad extends through the length of the district

FIG. 1. WATERSHED MAP OF ST. FRANCIS RIVER IN MISSOURI AND NORTHEASTERN ARKANSAS

east and west; the Paragould and Memphis and the Paragould and Southeastern enter it from the north; and there are several lines of railroad built to facilitate lumbering operations, which add largely to the total mileage. Some of the principal towns with their approximate populations are: Blytheville, 4,000; Osceola, 2,500; Marked Tree, 2,000; Lake City, 1,500; Luxora, 1,000; Manila, 800; Wilson, 500; and Burdette, 450. Jonesboro, on the west margin, one of the principal railroad centers of northeastern Arkansas, has a population of about 9,000. Memphis, just across the river from the heart of the district, the principal business center for the entire region, is the second largest city in the South.

HISTORY.

The St. Francis Valley, as well as the rest of Arkansas, was a part of the Louisiana purchase of 1803. Previous to the time of its cession to the United States the entire region was almost uninhabited, excepting, perhaps, a few settlers along the Mississippi River front; and for years afterwards it was visited only by hunters and trappers.

THE NEW MADRID EARTHQUAKE.

Among the earliest occurrences of historical importance in this region were the New Madrid earthquakes of 1811 to 1813, which are popularly supposed to have sunk large areas of land in the St. Francis Valley. Probably the fullest and most accurate record of this disturbance is that by N. S. Shaler, the noted geologist, in the Atlantic Monthly of 1869. The first earthquake, which occurred on November 16, 1811, at 2 o'clock in the morning, shook a larger area than any known disturbance except the Lisbon convulsion of 1755; and, in intensity, it was probably not surpassed by the movements which produced that great calamity. The disturbances continued until December 13, 1813, or for more than two years. In a description of this convulsion, given in the Popular Science Monthly for 1906, it is stated that during this time 1,874 separate shocks were recorded. Of the locality affected by the earthquake, Shaler says:

> There are reasons for believing that, although the center of the New Madrid earthquake shocks was at the outset very much west of the Mississippi, it gradually moved eastward until toward the close of these movements in 1813 it had traveled over 200 miles in this direction, being then near the mouth of the Wabash, on the Ohio.

The center of the disturbance at first was probably west of any civilized settlements. Indians describe even more terrible effects of the convulsion in the region between the Mississippi and the Great Plains. Everywhere the first movement seems to have come from the west, so it is necessary to refer the origin of this earthquake, as that of many other earthquakes of the same area, to some center of

disturbance lying between the Mississippi River and the Rocky Mountains.

Various records were made at the time, which indicate the great force of the shocks. The village of New Madrid was a complete wreck, even the solidly built log cabins being shaken down. Two falls were formed in the Mississippi River near that place; one being about 6 feet high, while the roar of the other could be heard 8 miles away, at New Madrid. So great was the disturbance of the river in that vicinity that of thirty loaded boats coming down the river when some of the more severe shocks occurred on February 12, 1812, only two escaped destruction. Whole forests fell prostrate. Reelfoot Lake in Tennessee had no existence before the time of this earthquake, it being formed by a sand blow at the outlet. Fifty years after the disturbance occurred Shaler found fissures 100 feet deep in Obion County, Tenn.

Of the records of this disturbance, Shaler says, "enough remains to make it certain that since human history began the earth has rarely been shaken by a more tremendous convulsion." He further states that "the disturbance was as unusual as it was severe. The valleys of the great rivers of the world, at least the parts immediately adjacent to their banks, are rarely the seat of earthquake shocks of great severity. The occurrence of such a shock in a region like the Mississippi Valley, on the borders of a great river, is probably unprecedented in the history of earthquakes." As in Shaler's opinion the results indicate that it may have been centuries since any other disturbance had occurred, we would not be justified in applying here the theory commonly accepted among students of the subject, that such disturbances repeat themselves as often as once in a century. In recent years there have been numerous slight shocks felt over this territory, but none which were severe. A repetition of this earthquake would affect principally the large cities where there are tall buildings, and would probably extend far beyond the limits commonly assigned to the New Madrid earthquake.

Such is the disturbance which is supposed to have originated the present conditions of the "sunk lands" of Missouri and Arkansas. The examination during this survey indicates that while this territory was always low and wet, the condition of a part was probably changed at the time of the earthquake. The most obvious example of this change is seen in Big Lake. The bottom of this lake contains a fallen forest of hardwood, of such varieties as usually grow on fairly dry ground, nearly all of the trees lying in the same direction. It is not clear, however, that this land was sunk by the earthquake. In the case of Big Lake it seems much more probable upon an examination of the local topography that the land west of the lake or at the outlet

was raised, thus shutting off the natural drainage and forming a lake. Over most of the territory on which the trees were destroyed a new forest growth is coming to maturity.

OWNERSHIP OF THE LAND.

At the time of the original government survey of this territory in the years 1845-1849, the greater part of the proposed district was reported by the survey as swamp land. By the swamp-land grant of 1850 these tracts were ceded to the State of Arkansas on the condition that the money received from their sale should be expended in their reclamation. Selections were made under this act and patents issued to the State of Arkansas from 1856 to 1871. By a compromise agreement between the United States and the State of Arkansas, approved by act of Congress of April, 1898, the State relinquished all its right to lands not included in any of the selections heretofore approved to the State. In 1893 the St. Francis levee district was organized by an act of the general assembly of the State, and all swamp land within the limits of the district belonging to the State, was transferred to the district. The levee district disposed of its entire holdings, and several hundred thousand acres are now owned by lumber companies in large parcels and the remainder is variously owned in smaller tracts.

Included in the district are several thousand acres of timbered land which was classed as "lake" in the returns of the original government survey. Recently the United States Government, through the Department of the Interior, laid claim to such areas in ranges 6 and 7, on the ground that, not being included in any of the descriptions of land ceded to the State, and never having been "lake" in fact, it still remains in the ownership of the United States as unsurveyed land. This claim was sustained by a decision handed down from the office of the Secretary of the Interior on December 12, 1908, and reaffirmed on February 27, 1909, and a survey of these lands has been ordered to determine what tracts will be affected by the decision. The total amount affected which otherwise would be reclaimed and assessed for the proposed improvement is very small, amounting to not more than 2 or 3 per cent of the area of the district. Only that part of the land along the St. Francis River reported as "lake" by the original United States government survey is included in this decision.

An act of Congress of March, 1909, recognized the validity of the claims of residents to Cane Island, near Lake City, and a survey has been made to establish permanent boundaries between the various owners.

DEVELOPMENT OF THE LEVEE SYSTEM.

While a narrow strip of land along the Mississippi River was so high as seldom to be overflowed and had been settled for many years prior to the construction of levees, the main part of the proposed district was covered with water to depths of 1 or 2 to 10 feet in time of the highest water, and its settlement for agricultural purposes was unprofitable.

In 1893 the St. Francis levee district was organized by an act of the state legislature, comprising the whole or parts of eight counties. The total area of the levee district is about 1,600,000 acres. With the help of the United States Government 165 miles of levee have been constructed, containing 20,132,000 cubic yards, at a cost of $3,380,000 for the actual construction. It is estimated that about 12,000,000 yards must be added, in addition to loops which may become necessary, in order to complete the work. At present about 10 miles of the levee is built to ultimate grade and about 60 miles is 3 to 5 feet below the ultimate.

For several years no overflows of the river have occurred within the leveed area. With the construction of the levees has come a great development of the lands of the district which formerly were overflowed, and it is believed that this development will continue until the entire area is reclaimed.

TOPOGRAPHY.

The St. Francis Valley is a nearly flat, wooded plain, lying between a low clay ridge, known as Crowleys Ridge, on the west and the Mississippi River on the east. There is a gradual slope away from the Mississippi River and from Crowleys Ridge toward the interior of the valley, which is 30 to 40 feet lower than the river front.

The important water courses of the district are the St. Francis River, the Right-Hand and Left-Hand chutes of Little River, Tyronza River, and Big Creek. Big Bay and Little Bay, on the west, and Pemiscot Bayou, on the east, are of less importance, and there are numerous other bayous near the Mississippi River. Pemiscot Bayou formerly carried overflow water from the Mississippi River and has built banks higher than the surrounding land. These higher banks continue down the Left-Hand Chute of Little River from the outlet of Pemiscot Bayou to the St. Francis River, and thence down the St. Francis River. West of the line formed by Pemiscot Bayou, the Left-Hand Chute of Little River, and the St. Francis River there are no channels in the district with high banks. In many parts of the district are shallow swales 1 to 3 feet deep and sometimes several hundred feet wide. A few shallow lakes are in the eastern part and some narrow and deeper ones near the eastern margin, which are probably old chan-

nels of the Mississippi River. The depression known as Big Lake is a large flat area which receives the waters of Little River in Missouri. It discharges through both the Right-Hand and Left-Hand chutes of Little River, and thence into the St. Francis River. Entering the district from the north, the St. Francis River spreads over a large flat area known as St. Francis Lake. Along the upper part of this lake the banks in many places are well defined, but along the lower part there is a gradual slope from the lowest bottom to the higher land of a foot to the mile or less. The high-banked channels of Pemiscot Bayou, Little River, and St. Francis River are very crooked, but the other channels in the interior of the district are fairly straight. In many parts of the district are sandy ridges 1 to 3 feet higher than the surrounding land.

CLIMATE.

The climate of northeastern Arkansas is similar to that of the Eastern States in the vicinity of Washington, D. C. The winters are short and generally mild, while the summers are long and often hot. The temperature ranges from a few degrees below zero during the coldest winter weather to more than 100° F. during the hottest periods of summer. The mean annual temperature is about 60°. The last killing frosts in the spring occur from the first of February to the last of April, while the first in the fall are from the last of September to the middle of November. Snow falls nearly every winter, but seldom remains on the ground more than a few days. The total yearly rainfall is about 47 inches, varying from 30 to 60 inches for different years. The wettest months are from January to June, while September and October are driest. The average rainfall for October is about half that for March. About ninety-four rainy days occur on the average each year, March having more than any other month. The lengths of seasons, extremes of temperature, and amounts of rainfall vary, of course, from year to year.

Northeastern Arkansas, being on the border between the North and the South, has a climate suitable for the production of many northern crops, while having seasons of sufficient length for the very successful production of cotton and rice.

SOIL.

Except for a comparatively small area along the base of Crowleys Ridge, the soils of this district are all composed of alluvium deposited by the Mississippi River, more or less modified near the surface by the addition of humus or decayed vegetation. Similar variations are found here as in other parts of the Mississippi alluvial plain; the texture varying from medium fine sand to fine clay, depending upon the velocity of the water in which the material was deposited. This

sifting of material has occurred in all parts of the district. As a rule the soil of the ridges is lighter than that of the lowlands. The subsoil consists of layers of clay, sand, and loam to depths of many feet, except along the west margin, where it overlies and is mixed with the loess or silt loam of the Crowleys Ridge formation.

Whether of heavy clay or of lighter sand the alluvial soils of this region seem to be almost uniformly fertile. Some small areas along the river front which have been cultivated for more than a century, with little or no care for the maintenance of fertility, seem to be almost as productive as land which has been in cultivation for only a short time. Newly cleared land produces exceptionally heavy growths of cotton for a few years, until the nitrogen of the top soil is reduced.

Thereafter, when the yield has become somewhat less, production continues with little further deterioration being evident. The sandy soils of the district contain enough of the finer soil particles to make them loamy, while the heaviest clays are more easily managed than sticky clay soils of other parts of the United States. But little difference is observed between the fertility of the heavier and the lighter soils. A few cypress brakes have a surface soil of muck or humus on top of the alluvium. These are among the most productive and most nearly inexhaustible of all soils in the South when properly drained. Their area in the St. Francis district amounts to but a few square miles.

Crowleys Ridge and the land immediately to the east is composed of a fine silt loam, commonly known as loess, very dense and nearly impervious to water. This soil, which has a nearly uniform texture throughout the area of its occurrence, was considered almost worthless until rice culture was introduced. As it proves to have just the qualities needed for this crop it is fast entering into that development which is making central Arkansas one of the great rice-producing sections of the United States.

NATIVE VEGETATION.

The native vegetation is an excellent criterion for judging the fertility of these soils. Canebrakes occur on the most fertile and best drained areas. A heavy growth of red gum, oak, ash, and other timber indicates lasting productiveness, while cypress and tupelo gum suggest great fertility but poor drainage. Stunted, scattering growths of post oak, willow oak, hickory, and locust indicate a soil of small agricultural value, except for rice. Very rank growths of underbrush and vines are seldom found on poor land.

The vegetation of the alluvial plain in the main corresponds to that of the wooded regions of Missouri, Indiana, and nearby States to the east, but the luxuriance of the growth indicates an equal

fertility of soil, a longer growing season, and a warmer climate. The entire valley was covered with timber at the time of its settlement, except for a few shallow lakes or marshes, which were overgrown with coarse grass, reeds, and rushes. The principal commercial woods are oak, gum, ash, cypress, elm, locust, and cottonwood. The forests formerly contained much walnut. Forest trees of all kinds attain a large growth, even persimmon and sassafras frequently being large enough for saw logs. Whenever large timber does not prevent the light from reaching the ground there is a heavy growth of underbrush, small trees, and vines. The courses of bayous and sloughs commonly are choked by bushes and small trees that are adapted to the wettest situations.

A few typical cypress brakes occur throughout the district, but they occupy probably less than 3 per cent of the lowland. In many places, however, cypress is found intermixed with oak, gum, and other timber. Tupelo gum is usually found about the edges of the cypress brakes.

One of the few evidences in this district of vegetation characteristic of the Southern States is seen in the canebrakes, which occur on the higher ridges. Here the growth is sometimes so dense that it can be penetrated only with difficulty without cutting a way. The cane, which is an evergreen, is excellent forage for stock, many cattle growing to maturity in the woods without any attention or care on the part of their owners.

Sluggish streams or ponds of dead water throughout the district usually are choked by pond lilies, water chinquapin, and other aquatic plants, though the main channels of the larger streams remain free from such obstructions.

The forest growth on Crowleys Ridge is for the most part limited to willow oak and stunted post oak, with occasionally small trees of other species.

The production of lumber is the most important industry of this section, and will probably continue to be important for fifteen to twenty-five years.

CROPS.

As in most other parts of the lower Mississippi Valley, cotton is the principal agricultural product, the acreage of which exceeds that of all other crops combined. The production on fairly well drained alluvial land varies from one-half bale or less to a bale per acre (500 pounds of lint to the bale) under the present methods of cultivation. It is certain that with thorough drainage and proper cultivation yields would be largely increased over the present average.

Next to cotton, corn is the principal crop, though as yet the production does not meet the local demand. Corn suffers more than cotton

from poor drainage, and for this reason its culture will never be completely successful until thorough drainage is secured. With such drainage the St. Francis Valley may become one of the important corn-producing sections of the country. Two crops of Irish potatoes are produced in a season, and as the product of the first reaches the market before the northern crops are matured it usually brings good prices. The alluvial soil of the valley is very well suited to potatoes, and an increased acreage is being planted each year.

Numerous clovers and grasses are planted as hay and forage crops, the most promising of which is alfalfa. On well-drained alluvial soil this legume makes a luxuriant growth, producing 4 to 6 tons of hay to the acre each season. As the price of alfalfa hay in the South varies from $10 to $20 a ton it is seen that this is a very profitable crop. Its chief enemy seems to be an excess of moisture, but when successfully established on well-drained soil it has proved to be more profitable than any other staple crop except potatoes. Tracts of high land along the Mississippi River front planted to alfalfa now command a cash rental of $10 or more an acre a year.

With the introduction of rice culture into central Arkansas there has been a great change in the market value of the heavy clay land along the base of Crowleys Ridge. Formerly thought to be almost worthless for agriculture, it is now much in demand, producing 35 to 80 bushels of rice to the acre. The western portion of this district is adapted to rice culture. For successful rice culture, however, drainage is very necessary, and until the thorough drainage of this part of the district is secured rice growing there will be a hazardous occupation, on account of the difficulty of plowing, seeding, and reaping.

Field peas are very generally planted, as throughout the South, in rotation with cotton and corn, as a fertilizing agent and for hay. Other crops which give promise are sweet potatoes, peanuts, onions, celery, and early vegetables for the northern market. Apples, peaches, and pears appear to do well on thoroughly drained soil, though little attention has ever been given to their cultivation.

LAND VALUES.

The principal factors which affect land values in northeastern Arkansas are: (1) The character of the soil, the alluvial land occupying the main part of the valley being valued more highly than the loess or silt-loam soil of Crowleys Ridge; (2) proximity to market and transportation facilities—the land along the Mississippi River front, along railroads, and on the best public roads being worth more than that lacking these advantages; (3) the value of timber, a very considerable part of the land in the district having a market value little greater than that of the standing timber; and (4) drainage. Except

along Crowleys Ridge and along the Mississippi River almost all the land in the district would increase in value if thoroughly drained. The present value of the cultivated land depends very largely upon its drainage. The best developed farms in the eastern part of Mississippi County are now valued at $100 to $150 an acre. They have a rental value of $5 to $10 a year for plow land and $10 or more a year for tracts planted to alfalfa. A large part of these higher priced lands are in need of more thorough drainage, and will not produce the best crops until they receive this improvement. Cultivated lands lying farther from the river front, which are frequently overflowed to such an extent that crops are destroyed, have a market value of $25 to $40 an acre. Cut-over land, which requires both clearing and drainage, can be bought for $10 to $20 an acre. Few tracts in the district are now sold for less than $10 an acre, except the heavy soils along the base of Crowleys Ridge. These can be bought for $5 to $20 per acre, depending partly upon the value of standing timber and the suitability of the surface for the cultivation of rice. This soil, also, will be greatly improved by drainage.

DRAINAGE CONDITIONS.

About 1,500 square miles of land in the proposed district are partially or wholly undrained. Of this amount something more than half is in Mississippi County, nearly a fourth in Poinsett, and the remainder is in Craighead, Cross, and Crittenden counties. A considerable amount of land along the Mississippi River front is now in cultivation, as are smaller areas in the interior, but very little is thoroughly drained. Nearly all land in the entire area upon which a crop can be made in favorable years either is in cultivation or is being cleared for that purpose; and much land is in cultivation which is so wet as to be unprofitable for crops. Perhaps a third of the district remains under water for weeks or months at a time during wet seasons, while the lowest parts are usually submerged for the greater part of the year.

Previous to the construction of the Mississippi levees little interest was taken in drainage. With the removal of this source of overflow interest in drainage began to develop, and several drainage districts were organized. As is usually the case when the first drainage improvements in an undeveloped country are undertaken, the people were not aware of the necessity for thorough drainage and sought relief only from the most intolerable conditions. The first systems made evident the beneficial results which would follow this improvement, and also served to indicate the necessity for more thorough work. During the last few years several drainage systems have been constructed. A number of the ditches are chiefly valuable as evidence that the best results will come only when plans are carefully devised and efficiently carried out.

During wet seasons the waters of Little River and the St. Francis River overflow a wide belt of country, submerging an area 25 miles wide east and west through the center of the district, the depth of water varying from less than a foot to 6 feet or more in different parts. Wherever a ridge of land rises above the line of high water it usually is occupied by settlers who are endeavoring to clear the land and farm it. Probably 80 per cent of all cultivated land in the district is seriously in need of drainage.

THE PROBLEM.

The great area of undrained and unimproved land in the St. Francis Valley presents exceptional difficulties to efforts at reclamation. The problem is how to improve this land so that the work will not be an undue burden upon the property owners, but will result in the fullest development of the region. In order to secure these results the improvement should be planned—

(1) So that as worked out the completed system shall conform to an economical, orderly, and effective plan, resulting in the fullest and best improvement of the region.

(2) So that it shall be possible to develop the district a part at a time as the interests of the valley require, not requiring one part which is ready for improvement unnecessarily to postpone development until the construction of the whole project may be undertaken.

(3) So as to secure all possible accessory results in addition to drainage; as water power, water transportation, rice irrigation, fisheries, and the improvement of road grades.

In accomplishing these results it will be necessary—

(1) To carry through the district all the drainage water from more than 4,000 square miles in Missouri and Clay and Greene counties, Arkansas, of which about 1,500 square miles is mountainous and hilly, with a very large flood run-off.

(2) To provide main drainage channels for carrying the drainage water of more than 1,500 square miles within the district itself.

(3) To plan a complete system of detail drainage.

(4) To provide a storage reservoir for the moderation of floods in the lower St. Francis.

In working out the plan it is necessary to examine carefully into conditions affecting run-off, or the amount of water which the system will be required to care for; hydraulic problems connected with the planning of drainage channels; construction methods and cost; the maintenance and repair of drainage constructions; and numerous problems connected with other subjects of interest. The conclusions reached in this report are based upon the facts and conditions described in the following pages.

RUN-OFF.

DEFINITION.

Of all the water which falls upon a given area as rain or snow, a part is returned to the air by evaporation from ground and water surfaces, or through the leaves of plants, while the remainder flows over or through the ground to streams, and thence passes out of the country as "run-off." The amount of water in an extensive drainage area which is permanently disposed of by being transformed into plant tissue, or by sinking so far into the soil that it does not reappear again at the surface for a great distance, is comparatively small.

UNITS OF MEASUREMENT.

In discussing run-off in its relation to rainfall, it is usual to express the rate in inches in depth in twenty-four hours over the entire watershed, or in cubic feet per second per square mile for the watershed area.

FACTORS AFFECTING RUN-OFF.

The chief factors affecting the rate and total amount of run-off are: Rainfall; topography; the size, shape, and location of the watershed; evaporation, and the transpiration of plants; climate and seasons; soil and geological structure; natural reservoirs, and the storage capacities of streams; the proportion of forest and open land, and the nature of the vegetable growth; the manner of cultivation of farm lands, and the particular crops planted; and artificial improvements affecting drainage. A discussion of these factors will indicate their influence upon run-off in the St. Francis drainage district.

RAINFALL.

This is the most important element to be considered in the estimation of run-off. A region of heavy rainfall also will be one of heavy run-off; and the variations in rainfall must be reflected in the amount of water which reaches the outlet channels. An examination of the rainfall records of twenty-two representative stations in or near the watershed in Missouri and Arkansas for the past fifteen years, or for such parts of that time as the various records have been kept, indicates that the mean annual rainfall for the drainage area during that period is 46.67 inches. Its distribution is irregular, however, both as to time and as to location. For instance, the annual rainfall may vary greatly at different stations. In 1893 the total rainfall at Cape Girardeau, Mo., was 28.81 inches, while at Brinkley, Ark., it was 58.52 inches. In 1899 the rainfall at Cairo, Ill., was 42.42 inches, and in New Madrid 66.01 inches. In 1902 the rainfall at Cairo was 33.07 inches and at Brinkley 57.65 inches. Variations in the amount

of rainfall for the same stations in different years are even greater than for the different stations during the same year. As example of this, Brinkley had a rainfall of 33.46 inches in 1901 and of 74.78 inches in 1906. At Corning, Ark., 24.48 inches fell in 1901 and 63.83 inches in 1898. At Pocahontas, Ark., 25.81 inches fell in 1901 and 68.04 inches in 1898. The average rainfall for the entire district also varies from year to year. The year of 1901 was "dry" with an average precipitation for all stations in the district of 31.48 inches, while 1906 had an average of 57.32 inches.

These and other comparisons, which can be seen in the following table, giving the annual precipitation for each station and the average for the district for each year, indicate the extreme variability even of the total annual rainfall. When the records are examined by shorter periods, much greater diversity is found. For instance, the rainfall over the watershed in Missouri for November, 1894, was 1.20 inches, while for the same month in 1906 it was 6.76 inches. Again, the rainfall during any month may be four or five times as great at one station as at another, and the variation in the rainfall between two stations during any given storm may be even greater.

Annual rainfall for each station in or near the district, with average for the disirict for each year, 1893 to 1908.

Station.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Birch Tree		42.07	50.96	34.91	55.28	56.43	39.63	41.33
Cairo	48.79	30.51	33.57	39.36	44.10	48.66	42.42	36.89
Cape Girardeau	28.81							
Caruthersville								
Farmington								
Goodland								
Ironton	46.47	43.60	37.77	49.13	57.80	60.80	43.93	46.62
Jackson								46.32
Marble Hill		41.60	42.29	47.26	52.58	60.09	44.02	50.58
New Madrid		44.61	48.68	58.92	55.69	68.40	66.01	55.68
Sikeston			41.57	44.43	49.78	65.30	54.78	39.42
Brinkley	58.52	53.92	51.99	43.62	51.51	59.64	47.77	51.25
Corning	43.80	42.39	37.50	44.96	43.19	63.83	41.76	43.54
Earl								
Forrest City	58.17	54.59	45.47	50.70	56.77	49.40		
Jonesboro					45.99	64.21	45.83	51.44
Luxora								
Marked Tree								
Memphis	44.45	54.52	38.59	35.00	46.03	48.89	38.99	47.42
Osceola	51.59	45.10	40.25	39.87		54.90	48.78	
Paragould								
Pocahontas			42.44	42.19	41.44	68.04	46.90	37.54
Average	47.57	45.29	42.59	44.20	50.01	59.12	46.74	45.67

Station.	1901.	1902.	1903.	1904.	1905.	1906.	1907.	1908.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Birch Tree	22.41	42.62	45.66	42.96	49.77	49.56	38.34	49.99
Cairo	31.68	33.07	32.91	32.00	39.48	46.92	45.58	38.47
Cape Girardeau								
Caruthersville			41.92	41.50	48.39	58.78	50.87	44.36
Farmington								44.30
Goodland					53.17	45.63	47.86	47.06
Ironton	28.71	43.40	40.32	48.22	63.67	49.63	43.69	52.49
Jackson	31.73	40.72	42.44	48.05	48.04	55.56	46.55	43.78
Marble Hill	30.01	37.98	36.40	43.89	48.64	58.89	50.57	49.76

Annual rainfall for each station in or near the district, with average for the district for each year, 1893 to 1908—Continued.

Station.	1901.	1902.	1903.	1904.	1905.	1906.	1907.	1908.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
New Madrid	38.33	44.60	40.54	42.30	50.40	59.92	54.09	47.99
Sikeston	39.22	40.44	41.98	44.56	48.14	56.51	53.78	47.89
Brinkley	33.40	57.65	35.24	42.31	62.95	74.78	58.75	43.06
Corning	24.48	48.08	46.14	38.14	....	63.53	....	46.70
Earl	....	....	....	....	....	....	....	....
Forrest City	....	54.47	38.98	43.14	64.13	62.95	52.37	....
Jonesboro	33.30	52.59	44.66	41.90	50.78	65.26	53.47	50.05
Luxora	....	....	....	....	40.77	....	37.63	....
Marked Tree	....	....	....	....	55.70	52.20	48.42	44.40
Memphis	34.58	50.32	35.56	42.56	55.85	54.31	41.55	47.46
Osceola	35.52	....	....	....	....	....	....	....
Paragould	....	....	44.83	....	....	....	....	....
Pocahontas	25.81	48.25	47.76	39.99	57.87	62.77	62.63	47.49
Average	31.48	45.71	41.02	42.25	52.36	57.32	49.13	46.33

Normal for sixteen years, 46.67 inches.
Greatest above normal, in 1898=59.12−46.67=12.45 inches.
Greatest below normal, in 1901=46.67−31.48=15.19 inches.

Yet, while rainfall records present these great variations, certain general tendencies are well defined. The months of March, April, and May are usually "wet," and August, September, and October are usually "dry," while the rainfall of the intervening months varies from year to year. The mean average rainfall for October, the driest month, over the entire watershed is about 2.5 inches, while that for March is about 5.5 inches.

As run-off is directly dependent upon rainfall, and as the rainfall which may occur at any time can not be determined within wide limits, it is seen that an exact determination of run-off is impossible. However, in order that drainage should be thorough, it must be sufficient in time of extreme storms; and if an examination of these indicates a certain uniformity of maximum rainfall, some intelligent conclusions may be reached as to the run-off to be provided for. In the table following is given a record of the 12 greatest storms in this watershed in a period of sixteen years.

Of the 12 storms recorded in the table, 2 occurred in November, 2 in December, 1 in December and January, 2 in January, 3 in March, 1 in May, and 1 in May and June. During the heaviest storm of this period, in November, 1906, an average precipitation occurred over the district of 7.3 inches in five days. During the next heaviest storm, in May and June, 1893, the average rainfall over the watershed in eleven days was 10.5 inches. The records indicate rainfalls of 6 to 7 inches in one day at single stations, but these extreme storms are usually local. The greatest daily amount for the entire district during this period was 2.6 inches. On sixteen days during the 12 storms recorded, the mean precipitation for the entire district reached 1.5 inches or more in twenty-four hours.

Record of the twelve greatest storms in the watershed of the St. Francis drainage district in the sixteen years from 1893 to 1908.

[From the records of the U. S. Weather Bureau.]

Year and day of month.	Birch Tree.	Cairo.	Cape Girardeau.	Caruthersville.	Farmington.	Goodland.	Ironton.	Jackson.	Marble Hill.	New Madrid.	Sikeston.	Brinkley.	Corning.	Earl.	Forrest City.	Jonesboro.	Luxora.	Marked Tree.	Memphis.	Osceola.	Pocahontas.	Average.	Number of stations with records.	Number of stations with rain.
1893.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
May 26		0.98					3.77		1.50				1.40			0.19			0.01	3.60		1.14	10	7
27		.40	0.50				.18		.47			3.65	.81		3.50	1.49			3.80	1.36		1.52	10	10
28		.82	.35				.06		.13			4.00	.98		3.20	.97			3.56			1.41	10	9
29			.30																			.03	10	1
30																							10	
31		.90	.45				.95		2.06			3.00	1.25		4.60	3.81			2.30	7.04		2.64	10	10
June 1		.64	.90				.10		(a)						1.45	(a)						.38	8	4
2		.66					.17		(a)			.70	.22		.87	(a)				1.14		.47	8	6
3		2.37	.80				.33		(a)			.60	.72		1.64	(a)			.04	3.46		1.25	8	8
4		.86	.60				.92		(a)				1.08			(a)						.43	8	4
5		2.10	.45				.22		(a)			.70	.67		.66	(a)				.90		.71	8	7
Total		9.73	4.35				6.70		(a)			12.65	7.13		15.92	(a)			9.71	17.50		10.47		
1894.																								
March 15	0.28	.08					.10								.08				.20	.10		.09	9	6
16										0.17		.25							.11	.62		.13	9	4
17																			.03				9	1
18	.48	.48					.25			.34			1.51		.95				1.19	.37		.62	9	8
19		.59								.52		3.00	.92		6.30				5.26			1.84	9	6
20	.50	.20					.23			1.72		3.90	.38		1.72				.81	2.05		1.28	9	9
21	.02	.18								.13		2.00	.05							2.08		.49	9	6
22	.80	.74					1.55			1.15		1.20	.71		1.29				.63	.34		.93	9	9
Total	2.08	2.27					2.13			4.03		10.35	3.57		10.38				8.23	5.56		5.40		
1897.																								
March 8	.06								.47	1.00		.20	.30		.38				.56	.16	0.73	.23	13	9
9	.39	1.52					1.23		2.12	1.88	1.69		.36		.10	.40			.02		.30	.77	13	11
10												.30	.05		.03	.46			.37	.12	.21	.12	13	6
11												1.10	.07		1.25	.19			.89	.63		.32	13	6
12												.10			.10				.01			.02	13	3
13												.25	.43		.35	.86			.50	.91	.34	.28	13	7
14															.63				.03			.05	13	2
15												.45			.12	.20			.03	.05		.11	13	5

16												.15	1.20		2.65	.55			.04	.22	1.12	.46	13	7
17	1.78	1.01					1.48		2.02	1.72	1.16	2.30	1.10		3.33	1.59			.89	1.50	.72	1.58	13	13
18	1.90	.39					.65			.82	1.00	2.15	.62		1.30	.65			2.39	2.22	.61	1.13	13	12
19	.65	.81					1.20		1.15	.50		1.20				.49			1.25	.48		.59	13	9
Total	4.78	3.73					4.57		5.76	5.92	3.85	8.20	4.13		10.24	5.39			7.59	6.29	4.03	5.72		
1898.																								
March 10	1.19	.02					.70		.68		.18		.27			.03					.56	.28	13	8
11	1.65	.32							1.34	.80	.47		3.30			.25					1.40	.73	13	8
12	2.52	2.58					2.10		2.49	2.50	2.37	1.20	1.16		.90	2.25			.08	1.03	3.40	1.89	13	13
13	.02	.23					1.65		.54		.84				.10	.02			.44		.08	.30	13	9
14		1.15										.30	.29									.13	13	3
15	.19	.11					.25		.18	1.50	1.04	.90			2.10	.56			1.71	.73	.18	.73	13	12
16	.12	.34					.12		.47		1.05								.01			.16	13	6
17	.17	.66					.25		.45	.30	.52	.80	1.13		.30	.11			.49	.27	.79	.48	13	13
18	.07						.18		.16	.80	.89					.03			.01		1.09	.25	13	8
19	1.25	2.20					.29		.27												.02	.31	13	5
20	2.24	.14					.09		1.76	1.55	2.50		.26			.15					.29	.69	13	9
21	.67						1.66		1.36	.20	.21		.03			.19				.05	.12	.35	13	9
22	.55	.17					.05						.03								.03	.06	13	5
23	1.18						1.67		1.12	.57	.22		.23		.40	.79			.07	.23		.50	13	10
24		.04								.10	.20	.38			.38	.09			.66	.30	.22	.18	13	9
25													1.47			.18						.13	13	2
26	.22	.78					.24		.90	1.00	.80		.38		.35						2.13	.52	13	9
27	2.31	.17					2.27		.88	.10	.23	.12	.75		.20	.90				.48	1.20	.74	13	12
28	.32	.29									.33	.50	.35						1.06	.22		.24	13	7
Total	14.67	9.10					11.32		12.60	9.42	11.85	4.20	9.65		4.73	5.55			4.53	3.31	11.51	8.65		
1900.																								
November 18		.04					.35	0.27	.28	.60			.53									.16	13	6
19	3.26	.30					2.40	1.04	1.59	1.20	.60	1.70	.07			.90			.65	1.00	.87	1.20	13	13
20	.07	1.51					.10	.47	.38	1.15	1.15	.90	.50			2.50			1.89	2.10	.37	1.01	13	13
21		.07								.15	.19					.01			.93			.10	13	5
22								.75														.06	13	1
23		.93					1.85	1.45	2.57	.85	1.39		2.50			.43			.01	1.50	1.20	1.13	13	11
24	1.36	1.73					.51	.95	1.01	4.55	1.58	3.65	.05			1.90			.57	3.90	.80	1.74	13	13
25	.38									.26									.53	.40		.12	13	4
Total	5.07	4.58					5.21	4.93	5.83	8.76	4.91	6.25	3.65			5.74			4.58	8.90	3.24	5.51		
1904.																								
December 23	.34	.22		0.41			.20	.76		.48	.33		.93			.94			.62		1.30	.44	15	11
24		.05		1.01					.20		.11	5.90	.03		2.00	1.06			2.74	1.40	.13	.98	15	11
25		.09								.27	.02	1.20	.18									.12	15	5
26		1.16		1.05				.56	.23	.26	.34	1.60	.75		1.25	1.20			3.91	2.00	.33	.98	15	13
27	.30	.40		.92			.20		.24	1.55	.67				1.95	.95			1.63	1.30		.67	15	11
Total	.64	1.92		3.39			.40	1.32	.67	2.56	1.47	8.70	1.89		5.20	4.15			8.90	4.70	1.76	3.18		

[a] No record.

Record of the twelve greatest storms in the watershed of the St. Francis drainage district in the sixteen years from 1893 to 1908—Continued.

Year and day of month.	Stations.																					Number of stations with records.	Number of stations with rain.
	Birch Tree.	Cairo.	Cape Girardeau.	Caruthersville.	Farmington.	Goodland.	Ironton.	Jackson.	Marble Hill.	New Madrid.	Sikeston.	Brinkley.	Corning.	Earl.	Forrest City.	Jonesboro.	Luxora.	Marked Tree.	Memphis.	Osceola.	Pocahontas.	Average.		
1906.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
November 17	......	3.70	......	3.25	......	1.15	2.00	2.30	1.72	1.25	2.83	1.91	2.48	......	0.58	2.00	0.80	......	6.54	......	2.50	2.33	15	15
18	......	.03	......	1.70	......	.13	.35	.02	.06	3.20	.94	2.64	.12	......	2.18	.20	1.20	......	.21	......	.02	.87	15	15
19	......	.71	......	.48	......	......	.25	1.05	.01	.12	.03	.18	.21	......	.22	.45	1.48	......	3.52	......	.09	.60	15	15
20	......	1.36	......	1.40	......	......	1.20	3.60	2.20	1.39	1.48	1.12	2.15	......	2.34	.40	1.52	......	1.34	......	2.80	1.62	15	15
21	......	1.71	......	2.15	......	1.89	1.20	.27	1.90	2.75	.13	2.83	1.25	......	2.44	2.80	3.00	......	2.50	......	1.50	1.89	15	15
Total	......	7.51	......	8.98	......	3.17	5.00	7.24	5.89	8.71	5.41	8.68	6.21	......	7.76	5.85	8.00	......	14.11	......	6.91	7.30	......	......
1906.																								
December 14	......	1.73	......	......	......	......	......	1.82	.69	......	.46	......	.73	......	......	......					.52	.35	17	5
15	......	.43	0.96	1.40	......	1.12	.95	.45	1.10	2.18	2.85	2.18	2.18	2.32	1.32	2.10	......	......	1.34	......	2.25	1.48	17	16
16	1.65	.43	......	.75	......	......	......	......	.28	.52	.60	.91	.67	......	.95	.80	......	......	1.13	......	.25	.53	17	12
17	......	.01	.30	.23	......	.25	.15	......	.18	.58	.18	.18	.25	......	.70	......	......	......	.08	......	.10	.19	17	13
Total	1.65	2.60	1.26	2.38	......	1.37	1.10	2.27	2.25	3.28	4.09	3.27	3.83	2.32	2.97	2.90	......	......	2.55	......	3.12	2.54	......	......
1906.																								
December 27	......	.08	......	......	......	.10	......	.06	.04	......	.28	......	.08	......	......	.05	......	......	.56	......	.05	.08	17	9
28	.03	.02	......	.03	......	.03	......	......	......	.08	......	......	......	......	.12	......	......	......	.08	......	......	.02	17	7
29	......	.87	......	......	......	......	.02	1.54	.03	......	.02	......	......	......	......	......	......	......	.40	......	......	.17	17	6
30	.70	1.88	1.96	2.05	......	.71	1.12	......	1.62	3.80	2.68	3.14	2.41	3.10	2.23	2.20	......	......	1.11	......	2.70	1.97	17	16
31	......	......	......	......	......	......	......	......	......	.05	.16	......	......	......	......	......	......	......	......	......	......	.01	17	2
1907.																								
January 1	......	.42	1.02	......	......	......	......	.40	......	......	.85	......	......	......	......	......	......	......	.01	......	......	.16	17	5
2	.46	2.51	4.10	2.55	......	......	.15	1.70	1.68	3.10	2.00	1.54	3.40	1.25	......	2.40	......	......	.42	......	3.55	1.81	17	15
3	.43	1.87	1.02	4.42	......	.81	1.20	2.42	2.30	2.50	3.04	.93	2.96	2.85	......	2.80	......	......	1.10	......	2.98	1.98	17	16
4	.02	......	......	.03	......	......	.10	.11	.10	1.00	.08	.48	.05	......	......	......	......	......	......	......	.07	.12	17	10
Total	1.64	7.65	7.08	9.08	......	1.65	2.59	6.23	5.77	10.33	8.91	6.09	8.90	7.20	2.35	7.45	......	......	3.68	......	9.35	6.24	......	......

1907.																								
January 21	2.52	2.94	1.60	2.80			.60	1.11	2.60	.03	2.27	2.61	2.64		.55	3.28		0.40	3.44		3.05	1.80	18	16
22	.80	.28	1.80	1.88		2.59	2.20	2.64	1.56	4.11	1.73		1.01		4.15	1.45	3.60	2.00	.35		.75	1.79	18	17
23		.01	.04							.04								1.30				.07	18	4
Total	3.32	3.23	3.44	4.68		2.59	2.80	3.75	4.16	4.18	4.00	2.61	3.65		4.70	4.73	3.00	3.70	3.79		3.80	3.66		
1907.																								
May 3	.50	.09		.47	0.20	.35	.02	.06			.10		.48		.02	.50		.23	.01		.50	.20	18	14
4					.10		.30			.25					.10			.47				.07	18	5
5	1.00	.96		.85	.45			1.43			.81		.80						.82		.44	.42	18	9
6	1.60	1.66	1.54	2.83	.70	1.07	1.20	.55		2.55	1.12	4.87	1.75		3.80	2.50		3.13	3.07		1.77	1.99	18	17
7	.63		.90	.47		.43	.55			1.50	1.05	1.12	1.34		.78	.55	.70	1.11			1.50	.70	18	14
8	.20	.52	.01	1.08	.32	.22	.10	.55		.54	.71	1.46	.38		1.75	.58	.20		.68		.28	.53	18	17
9			.04	.45			.17			.44	.22						.70					.11	18	6
10		1.25	.50	2.10	.40	.35	.40	.70		.45	1.10		1.35			.50		.78	.07		1.52	.64	18	14
11			.30				.10			.88					.04		.48					.10	18	5
12																							18	
13																							18	
14	1.44	.92		.61	3.00	1.24		1.50			.58		.74					.67	1.28		.67	.70	18	
15		.03	1.10	.50	1.50		1.25			.72	.40	1.06	.34		1.25	1.01	1.10	.43			.10	.60	18	
Total	5.37	5.43	4.39	9.36	6.67	3.66	4.00	4.24		7.33	6.09	8.51	7.18		7.74	5.64	3.18	6.82	5.93		6.78	6.04		
1908.																								
January 11												2.00			2.00	2.06			1.97		.75	.88	10	5
12												.50				.29			.05			.08	10	3
13												2.10				2.37					.25	.47	10	3
14															2.10	.03			1.77		1.53	.54	10	4
15																			.07		.04	.01	10	2
16																							10	
17																							10	
18											.13											.01	10	1
19	.60	1.65					.53		.96		1.92	2.70			2.10	2.15			2.58		1.29	1.65	10	10
20	.08	.61					.85		.88							.02			.02		.54	.30	10	7
21											.44											.04	10	1
22	.48	1.27					.65		.61		.63	2.40			2.00	1.02			2.65		.68	1.24	10	10
23																							10	
24	.22										.27											.05	10	2
25		.17					.25		.12													.05	10	3
Total	1.38	3.70					2.28		2.57		3.39	9.70			8.20	7.94			9.04		5.07	5.33		

The relation of rainfall to run-off depends upon numerous factors discussed below, but it may be said in general that in this region during a heavy storm from 25 to 80 per cent of the rainfall in the various sections will enter the streams as run-off, the least proportion occurring in loose and well-drained sandy soil having a large storage capacity and the greatest in hilly or mountainous regions.

TOPOGRAPHY AND GROUND SURFACES

It is very evident that hilly and mountainous land will have a greater rate of run-off during storms than will flat land, and, in fact, this difference is very marked in many instances. There are obviously no distinct lines between the different classes of topography, but in general three characteristic divisions may be noted. First is the rugged or precipitous mountain and hill land, from which the run-off is torrential. Here the streams, which form narrow gullies between ranges of hills, have steep channel slopes of 2 to 10 feet or more to the mile. The water which falls as rain finds its way to the gullies and water courses, and within a few hours after falling is in the main channels on its way to the outlet. In such cases the extreme flood at the outlet from an area of 500 to 1,000 square miles may occur six to twenty-four hours after the heaviest rainfall. From such areas a run-off of an inch in depth over the entire watershed in twenty-four hours is not uncommon, while run-offs of 2 and even 3 inches in twenty-four hours have been recorded. The second class includes areas which, while not uniformly precipitous, are rolling, have surface slopes of 10 to 50 feet to the mile, and are cut by numerous streams or gullies. Here the water gathers quickly after storms, and the extreme flood flow from areas of 500 to 1,000 square miles may occur in one to three days after the time of greatest rain. From such areas, run-offs of one-half to three-quarters of an inch from the entire watershed in twenty-four hours are not uncommon in the central United States, and run-offs of twice this amount sometimes occur. The third class includes flat lands having little or no appreciable surface slope. Here the maximum rate of run-off depends very largely upon other conditions which will be discussed, and may vary for areas of 500 to 1,000 square miles from 0.05 to 0.30 inch in twenty-four hours.

Aside from the general topography, the condition of the ground surface has much to do with the rate of run-off. A clean surface, over which the water can find its way without difficulty, and one filled with gullies and small channels, will have a quicker run-off than a surface covered with loose rock and débris and having no well-defined channels for carrying water.

THE SIZE, SHAPE, AND LOCATION OF WATERSHED AREAS.

Large watersheds may be counted on as having lower rates of run-off than smaller ones: First, because most extreme storms are usually local, so that where an area of 50 square miles may have a rainfall of 3 inches in twenty-four hours, an area of 1,000 square miles during this same period will probably have an average precipitation of not more than half that amount. This localization of extreme rainfalls is so general that it may be depended on in calculating run-offs of very large areas; second, in a large watershed local conditions as to topography and other factors influencing run-off counterbalance each other. A small area may happen to combine many elements which tend to produce a large run-off, while in larger areas some parts will have larger run-off than others, and that of the area as a whole will be less than that of portions having the more extreme conditions; third, the run-off of the various parts will never coincide exactly in point of time. That is, on account of the difference in length of time required to reach the outlet, the water falling nearest the outlet will pass away before that from a greater distance, and so the flood flow will be moderated. Formulas for estimating the rate of run-off according to the size of the watershed find their justification in these facts.

The shape and location of a watershed also affect the rate of run-off. A drainage area having a fan-shaped outline, with numerous tributary channels uniting to form an outlet at the small end of the fan, will have a comparatively high run-off, because water from the greater part of the area will be concentrated in the main channel. On the other hand, in a long, narrow drainage area the flow will be distributed over a longer time, on account of the difference in time required for the water in different parts to reach the outlet.

EVAPORATION AND THE TRANSPIRATION OF PLANTS.

As practically all water falling upon a drainage area either passes out of the district in its water courses or is evaporated, it is seen that evaporation is a very important factor to consider in planning drainage improvements. While the knowledge of the subject is somewhat limited, it is believed that in the lower Mississippi Valley evaporation from water surfaces amounts to from 2 to 4 feet in a year. The rate of evaporation is very much greater in summer than in winter, in windy than in still weather, and is more rapid from exposed surfaces than from those which are sheltered. In the lower Mississippi Valley, as a rule, the wet season occurs during the winter and spring, when evaporation is least, and the run-off of this season is correspondingly large.

Probably the greater part of the water evaporated from the St. Francis drainage area is that which is removed from the soil by

plants, and is evaporated from their leaves. This process is commonly called transpiration. While studies and estimates of the water removed by growing plants have been made for many years, only the most general knowledge of the subject is available. It has long been noted in the warmer parts of the United States that when the leaves come out in the spring the water level in many streams and swamps begins to fall, while the dropping of the leaves in the fall is commonly accompanied by a definite rise of from a few inches to a foot or more in the water levels of streams and sloughs. Careful experiments have been made in France, southern Russia, and India to determine the difference in ground water level at the end of the growing season in tracts of forest and of cleared land lying side by side and similar in all other respects. It has been found that at the end of the growing season the ground water level in wooded tracts may be from 2 to 12 feet lower than that of open tracts adjoining, this difference being due to the removal of water from the soil by forest growths.

In addition to the amount of water taken from the soil and evaporated through the leaves of deciduous forest trees a considerable amount of the summer rainfall, estimated by forestry experts at perhaps about 40 per cent, never reaches the soil, but being caught by the leaves is again evaporated into the air.

It is seen, therefore, that the amount of rainfall to be carried away by the drainage system of a forested area is less for the entire year than from a similar area of cleared land; and that a drainage system which is abundantly sufficient for forest areas may be found to be too small when the land is cleared and put into cultivation. It often happens, however, that the surface of the soil dries out more quickly in cleared and cultivated land than in woods. This is because cultivated land usually has surface ditches or other provisions for carrying rain water to run-off channels, and because the surface soil dries out quickly in sun and wind, whereas in woodland water taken up by roots is from the lower soil.

CLIMATE AND SEASONS.

As stated before, the flood run-off of this region is large because the rainy season occurs in the winter and spring season, when evaporation is low. It happens also that in the spring, when the accumulated water of the winter season is still on the ground, the soil must be cultivated. At this time, also, young plants of cotton and other crops will most easily be damaged. It is necessary, therefore, in planning a drainage system, to provide for thorough relief during the spring months; and a system which is sufficient for this season will be adequate for all other parts of the year.

SOIL AND GEOLOGICAL STRUCTURE.

The run-off of this region is very greatly influenced by the character of the soil. The heavy loam clay of Crowleys Ridge and the adjoining territory absorbs very little water, and nearly all that falls as rain either passes off in the flood flow or remains on the ground until it is evaporated. The stream channels in this soil carry very little water, except immediately after rains. In the sandy lands of southeastern Missouri, however, a very different condition exists. Here the drainage ditches carry a very even flow throughout the entire year, the greatest in some of them being not more than three or four times the least. Careful observations in the St. Francis drainage district lead to the conclusion that the run-off of most of that area, except along Crowleys Ridge, and in some places near the Mississippi, while not so well distributed as that of southeastern Missouri, will yet be quite nearly uniform. An instance of this condition was noted while the survey was in progress. In November, 1908, 4 inches of rain fell in twenty-four hours, following a long dry spell. On Crowleys Ridge and over the region of clay soil, flood conditions at once followed. Several highway bridges were washed away, and considerable damage resulted from high water in the streams. On the day following the rain, careful observations were made as to the results of the rain storm, and similar information was secured from men in the field. The investigation developed that this very heavy rain, which had resulted in flood conditions in clay regions, had produced almost no run-off whatever on the lighter soil of the interior of the district, but passed immediately into the soil, except where the ground was already saturated. It seems, therefore, that in the lower parts of the region having a sandy soil, drainage ditches will have a fairly uniform flow of ground water, and that sudden floods after heavy storms will not occur.

NATURAL RESERVOIRS AND STORAGE CAPACITIES OF STREAMS.

The St. Francis watershed has very few natural depressions and channels which will serve to moderate flood flow. The most important is the channel of the St. Francis River from the point where it leaves the Ozarks to the northern boundary of the district. So far as their storage capacity is concerned, the ditches and channels within the district, except the floodway and reservoir system, will have very little effect upon run-off.

FORESTS.

The increase of evaporation due to forests has already been referred to. They tend to reduce moderate floods, moreover, by obstructing the water as it flows over the surface of the ground,

requiring a longer time for it to reach outlet channels. In many parts of the South a cutting away of the forests has resulted in a vast amount of hillside erosion, and this, in turn, has caused floods to be more torrential. A careful examination was made of the upper watershed of the St. Francis River to determine what would be the effect of a further clearing away of the forests of that region upon floods in the river. The conclusion was reached that little hillside washing would take place, and that no noticeable increase of floods would result from such a change. About the town of Iron Mountain, Mo., the forests were formerly cut off to produce charcoal for smelting purposes. It is said that in this charcoal production all parts of the trees were used, and even the leaves were raked together and used in making the coal pits. Yet over this area a new growth has come up, and little evidence of hillside washing exists. It seems safe to assume that flood conditions in the hill regions of the St. Francis River will not be changed materially in the future.

MEASUREMENT AND ESTIMATION OF RUN-OFF.

After taking into consideration the factors which affect run-off, and after examining the records of run-off of other watersheds in drained and undrained land, estimates were made of the amount of water which must be carried from this watershed by a completed system of drainage.

The entire drainage area was divided into four parts in estimating the rate of run-off, as follows:

The flat lands of the main drainage area; the clay lands east of Crowleys Ridge; Crowleys Ridge; and the watershed of the St. Francis River in the Ozarks.

In estimating the run-off from the flat lands of the district it is assumed, as a result of these investigations, that the rainfall for the entire district will not exceed 12 inches a month, and that for large areas of well-drained land not more than half of this maximum rainfall will run off during any one month. The run-off for these flat areas was estimated by the formula $C=\frac{24}{\sqrt{M}}+6$, in which C equals the run-off in cubic feet per second per square mile, and M equals the drainage area in square miles. The largest areas to which this formula is applied are those draining into the Tyronza River and into the old channel of the St. Francis River. Here the drainage areas are 400 and 310 square miles, respectively, and the estimated rates of run-off are 7.2 and 7.4 cubic feet per second per square mile, or a little more than a fourth of an inch from the entire watershed in twenty-four hours. Rates of run-off per square mile for other areas according to this formula would be, 100 square miles, 8.4 cubic feet per second; 50 square miles, 9.4 cubic feet per second;

10 square miles, 13.6 cubic feet per second. The rate of run-off will vary to a considerable extent in different parts of the interior of the district, being greater from clay land in cultivation in the vicinity of Luxora than from sandy woodland in the interior. It is believed, however, that the formula given above will approximately indicate the run-off from exceptionally heavy rains for the more adverse conditions throughout the area to which it is applied. A more detailed examination of the soil may indicate many minor variations, especially in the rate of run-off from the lighter soils, which probably never will reach that indicated by the formula.

The rate of run-off from any given tract will change from year to year as clearing and cultivation increase and drainage becomes more thorough. It is impossible to estimate with exactness how the different factors which affect run-off will balance each other, or just what changes in run-off conditions will occur in the future. In planning the drainage system, therefore, a factor of safety is used to insure the drainage channels being large enough, even under adverse conditions.

An examination of that part of the district just east of Crowleys Ridge indicates that this area will have a far greater run-off than the main part of the district. The soil here is a dense clay loam which absorbs very little water, and, with a considerable surface slope to the east, the run-off is comparatively rapid. The flood discharge from this area is estimated to be twice as great as that from the main part of the district above described. On Crowleys Ridge the run-off will be still greater, as here are an impervious soil, steep surface slopes, and numerous gullies to serve as drainage channels. The run-off of this part is estimated to be three times as great as that from the main part of the district. It is quite probable that a more extended investigation will indicate a still greater run-off for Crowleys Ridge. However, it seems possible to construct collecting ditches along the base of Crowleys Ridge, with continuous waste banks on the east side, so that the ditches as planned will be fully sufficient.

In estimating the hill run-off of the St. Francis River in Missouri comparison was made with the flood discharges of many mountain and hill streams. Visits were made to the mountain and hill areas drained by the Connecticut, Kennebec, Merrimac, and Hudson rivers in the northeastern part of the United States; the Potomac in Maryland and West Virginia; the Little Wabash in Illinois; and the Cold Water and Tallahatchie rivers of Mississippi, on all of which streams flood measurements had been made, and comparisons of the watersheds of these streams with that of the upper St. Francis were made.

Extreme flood flows from these streams have varied from half an inch to 3 inches or more from the entire watershed in twenty-four

hours, according to the best available records. The highest rate has been recorded only on streams draining precipitous hilly or mountainous regions, or where melting snow has added to the run-off.

The mountain drainage area of the St. Francis consists for the most part of rounded hills or low mountains, separated by valleys from a few hundred feet to a mile or more wide. The valleys are not flat, but have a surface slope of 10 to 100 feet or more to the mile toward the stream channels. Perhaps three-quarters of the surface is wooded, and may remain so for many years to come. The soil over much of the area is clay or disintegrated quartz rock. Floods from melting snows have seldom if ever occurred. The drainage area in the hills is about 1,500 square miles. The watershed is long and narrow, the distance from the source to the upper end of the proposed district by the river channel being perhaps 250 miles, though the river when leveed will receive no drainage along the lower half of this distance. As stated under the discussion of rainfall, the greatest rainfall recorded over the area of the upper St. Francis Valley during the past fifteen years was 2.6 inches in twenty-four hours, and 1.5 inches a day for five days. As from three to five days are required for water from the extreme upper end of the watershed to reach the district, and as the floods are modified in flowing this distance by filling up the channel, it seems safe to say that not more than an inch of water in twenty-four hours from the entire hill area will ever reach the upper border of the proposed drainage district. This amount compares favorably with the results reached by a comparison of this watershed with the others mentioned. In order to provide a factor of safety for extreme storms, it was decided to estimate the flow at the base of the mountains as follows:

A uniform high-water flow of $\frac{1}{4}$ inch in twenty-four hours from the entire watershed is assumed, increasing to the following storm run-off: First and second days, $\frac{1}{2}$ inch run-off; third day, $\frac{3}{4}$ inch; fourth day, 1 inch; fifth and sixth days, $1\frac{1}{2}$ inches; seventh day, 1 inch; eighth day, $\frac{3}{4}$ inch; ninth and tenth days, $\frac{1}{2}$ inch. Continued storm run-off of $\frac{1}{4}$ inch.

It is believed that this assumed case will cover the greatest storm which will ever occur over the watershed. However, the levees of the floodway and reservoir are planned to be of such height and dimensions that 50 per cent could be added to this run-off without endangering them.

The run-off from this hill area may never be more than half the amount estimated, but where exact information can not be had the only safe course is to plan the work of such dimensions as to make failure practically impossible.

Further surveys and investigations may indicate the advisability of reducing these estimates of run-off to some extent. Gaugings

were not taken on the upper St. Francis River during the survey because of lack of funds. Such gaugings, if made, would be of but limited service, because, in order to insure the absolute safety of the floodway and levee system, it is necessary to provide, not for the greatest flood of a season, but for the greatest which may occur at any time in the future. A series of gaugings would have furnished a basis for comparison, and it is hoped that they may be made as part of a complete survey.

CHANGES WHICH WILL OCCUR IN RUN-OFF CONDITIONS.

In many drainage districts it is possible to estimate the future run-off by that which has occurred in the past, but in this case such a course is not possible for the following reasons:

(1) The plans of the Little River drainage district in Missouri include provisions for diverting the run-off from 1,500 square miles of hill area from the Little River Valley and into the Mississippi River at Cape Girardeau. This will tend to lessen the flow in the Little River channel.

(2) The plans for the Little River district contemplate, also, a complete system of drainage for the flat lands of the district, carrying all of this water to Big Lake at the state line. The tendency of this work will be to cause a quicker run-off and to create flood conditions in Arkansas.

(3) Numerous other ditches are being constructed in Missouri which will tend to aggravate flood conditions at the state line.

(4) At present a large part of the mountain drainage of the St. Francis River in Missouri overflows that channel through some low breaks in the bank, and reaches Black River or Cache River. With the leveeing of this stream this water, which now never reaches the district, will be held in the channel, and other water which now overflows the channel on the east side will reach the district more quickly on being restrained.

(5) The St. Francis reservoir will restrain and regulate floods, causing a lower maximum flow in the lower St. Francis than would occur were the district planned without a reservoir.

(6) Under present conditions the entire interior of the district acts as a storage reservoir during the wet season, as it is overflowed to a depth of several feet. The drainage and protection of this land will tend to increase the discharge from the district.

(7) The clearing and cultivation of the land will change run-off conditions very materially, probably tending to increase the maximum flow in the ditches.

(8) The completion of the proposed drainage system will change the run-off conditions throughout the district, increasing the rate

from areas of heavy soil, and perhaps causing a slower run-off from light sandy soils.

The total effect of all these changes can not be ascertained definitely in advance of their occurrence, but it is certain that run-off conditions in the future in this district can not be judged accurately from those which exist at present.

CONSTRUCTION METHODS AND COST.

GENERAL PHYSICAL FEATURES.

The St. Francis Valley within the proposed district is a flat plain with few local irregularities. The network of bayous and brakes characteristic of alluvial lands farther south in the Mississippi Valley is lacking here. The lateral ditches will be quite uniform in depth, ranging with few exceptions from 7 to 10 feet. Many of the shorter ditches can be dug either upstream or downstream as is more convenient. By a proper planning of the construction sufficient water for floating dredges can be had in nearly all parts of the district. On the other hand, by working upstream from the lower end sufficiently complete drainage can be secured for constructing the levees and ditches along the floodway with land machines. Perhaps 90 per cent of the proposed work is in wooded land. As the main drains and floodways are located on the lowest land, the heaviest timber will not be encountered over a large part of the main system. In the construction of lateral ditches the ordinary timber of the country must be removed.

The numerous railroads afford a means for supplying fuel to the excavating machines, but very few railroads of importance will have to be crossed on the work. The few wagon roads in the interior of the district are in poor condition during most of the year. The first six months of the year cover the wet season, while August, September, and October are usually dry. It is customary to operate dredges throughout the entire year, but conditions for work are most unfavorable during July, August, and September, and it might be found profitable to stop work during this period, allowing the working force to spend those months where sanitary conditions are more favorable. During other parts of the year health conditions are as good as in any other part of the country.

CHARACTER OF EARTH.

Perhaps 90 per cent of the excavation required on this project is in the ordinary alluvial soil of the upper St. Francis Valley, and a description of this type will indicate in general the soil conditions to be encountered. This soil contains absolutely no rock and no hardpan. The partial investigation made and the experience of dredge

men indicate that little if any sunken timber will be encountered. The soil itself varies from a stiff clay to a light sandy loam. In some places there are considerable bodies of sand, but as a rule this occurs in thin layers, alternating with loam or clay.

With one or two exceptions which could not be avoided no ditches in the entire system were planned to be more than 10 feet deep. Perhaps 50 miles of ditches have already been constructed in various parts of the district. Generally the ditch banks remain permanently in about the same condition as they appear a year after construction; during construction, as a rule, they do not cave to a serious extent, and the filling of the ditch during construction is not a serious matter. The waste banks hold their shape with side slopes of 1 or 2 to 1 for indefinite periods.

About the only opportunity in the interior to observe the ability of the ground to hold a fill, such as the levees which are planned along the floodway, is seen where the St. Louis and San Francisco Railroad crosses the St. Francis bottoms. Here a fill of 20 feet or more extends through the lowest and wettest lands of the district. No tendency to unusual settling or to a bulging of the adjacent ground has been observed on this road. At a point on the Iron Mountain Railroad east of Parkin a fill has caused the adjacent ground to slide and to bulge upward to a height of 6 feet or more. It is doubtful if this difficulty would have occurred had a fill been constructed with as flat side slopes as are planned for the floodway levees. However, it may be that at some points along the line of the proposed floodway this difficulty will be met, and a survey for definitely locating the floodway should include a careful examination of subsurface conditions, with the object of avoiding, as far as possible, any construction on an unstable foundation. It is believed that such a location can be made without materially increasing the length of the levees.

Considered as a material for levee building, this soil will compare favorably with that along the Mississippi River front, of which the river levees are constructed. They will not, however, be subjected to as severe tests as the Mississippi levees, as the larger floods will occur only once in several years and will last but a few days, so that the levee sections will not become saturated except at the base.

The fact that most of this area is timbered adds to the cost and difficulties of excavation to such an extent that the contract price will, on the whole, be perhaps 1 cent a yard higher on account of timber; but, aside from this factor, it is the opinion of dredge men of large experience in this region that no better soil for dipper dredge excavation is found in the United States. For hydraulic dredge excavation the only adverse factor in the soil conditions is the cost of removing stumps and roots, and the same may be said of excavation by drag scraper excavators.

THE COST OF CLEARING.

Almost all the proposed work is through wooded land. Over the route of a part of the ditches the trees are small and scattering, and the clearing of right of way will be a small item; over a large area the timber is the usual hardwood growth found in that region, while in a few instances the right of way follows cypress brakes where clearing will be difficult.

It is assumed that in clearing the right of way for the floodways and for the larger ditches, skidding machines or other devices for removing timber will be used. Along the line of the floodway it may prove economical to construct a light temporary railroad for removing timber and facilitating the clearing. The clearing of right of way by cutting stumps low and removing or burning trunks and branches is estimated at $20 per acre for all the work proposed, excepting lateral ditches to be constructed with dipper dredges, in which case the clearing of right of way is included in the cost of excavation. About 25 feet of the levee base will be cleared of stumps in digging the muck ditch with a dipper dredge. As most of the levee base will be continually wet, and not alternately wet and dry, as is the case with the Mississippi levees, it is not thought necessary to grub stumps for the remaining part, except those of cottonwood and other similar timber which decays most quickly. Other stumps should be cut close to the ground.

It will be necessary to remove stumps from the ditch section in order to operate successfully either suction dredges or drag scraper dredges. Such clearing is estimated to cost $150 an acre in addition to the excavation. Very little cypress will be found along these ditch lines and most of the other trees have shallow roots. Little or no timber is believed to be at a distance below the surface.

In making an estimate of the cost of clearing timber from the right of way, the principal lumbering firms of the district were consulted, and the opinion was expressed by nearly all of them that the work can be done for less than the estimate used in this report.

FUEL.

Wood is available for fuel in nearly all parts of the district, at a cost of 75 cents to $1.25 a cord, delivered on the right of way. It is expected that wood may be used for fuel in constructing the lateral dredge ditches wherever the work is not so located as to make other fuel readily available.

Coal costs $3 to $3.50 per ton delivered at the stations of the district. In the excavation of the main drains, with proper management in arranging the sequence of the construction, coal can be delivered by barge to nearly all parts of the work. Where it can not

be so delivered, some other fuel would probably be used. In all of the work proposed for a hydraulic suction dredge, coal could be delivered to the dredge by barge, and the same is true of most of the larger dipper-dredge work. In the construction of the work upstream by means of drag-line scrapers, some difficulty might be encountered in getting coal to the boat by barge, but it is believed that this would not be serious.

Oil is available for fuel from the oil fields of Louisiana, Texas, Oklahoma, Kansas, and Illinois; several oil fields being about equally distant.

EXCAVATING MACHINERY.

Of the many types of excavating machines now in use only a few are especially adapted to the work of this district. Among these are floating dipper dredges, drag-scraper excavators, and hydraulic suction dredges. It is possible that an endless-chain levee-building machine might be adaptable to the construction of the floodway levees.

THE DIPPER DREDGE.

The advantages of the dipper dredge over other types of excavators are: Its adaptability to all conditions of excavation where there is sufficient water to float the boat; its great strength for digging tenacious soil or in removing stumps and roots; and the low cost of excavation by its use. The disadvantages of this type are: Its inability to construct ditches of less than about 100 square feet cross section; the necessity for floating a large boat; the ragged and uneven cross section which is usually left; the practical limitation of the machines to ditches of not more than about 800 feet cross section; and the insufficient berm which is of necessity left on the larger ditches. Small dredges of light construction are made to float on boats with 10 or 12 foot hulls, but as they are not adapted to excavation in timbered lands, their use is not advisable in the St. Francis Valley.

No machine is so well fitted as the floating dipper dredge for digging all but the largest of the lateral ditches on this project. It has been adapted by long experience to this class of work.

The cost of construction with the floating dipper dredge varies according to the section to be excavated, the total amount of excavation on a job, the amount of water available, the character of the excavation, the timber to be encountered, and the type of the machine. The actual cost to the contractor of excavating with a high-grade modern dredge in a timbered region where conditions of soil and water supply are favorable, and where a large piece of work is suitable for the machine, should be from 3 to 5 cents per cubic yard,

including clearing of the right of way, repairs, and maintenance. This project furnishes a large amount of work where every feature is favorable for most of the ditches, except the necessity of clearing the right of way, and, in some instances, the difficulty of procuring water during the entire year; and it is believed that under these conditions an estimate of 8 cents per yard for this excavation is conservative. Work is now being let in this region for from 7.5 cents to 8.5 cents per yard, including the clearing of right of way.

THE DRAG-SCRAPER EXCAVATOR.

This type probably will not be used except in building the levees along the floodway. Where a section of levee is of less than 800 square feet it can probably be used to better advantage than any other excavator after the ditch section is cleared of all large stumps.

One of the more successful types of excavators used on the New York Barge Canal is similar to that illustrated in Plate I, figure 1. The scraper bucket is suspended by cables from the end of a long boom. The entire machine swings on a circular turntable. The bucket is filled by pulling it directly toward the center of the machine by means of a cable, so there is no strain on the boom except that due to its own weight and the weight of the bucket and its load. As a result, the booms of this type of machine can safely be made lighter and consequently longer than is the case with the booms of dipper dredges of similar size and strength. A boom 90 and perhaps 100 feet long giving a reach of 100 or 110 feet from the center of the machine to the end of the boom is practicable with this machine. An excavator of this type on the New York Barge Canal which was carefully examined has an 85-foot boom and a reach of 96 feet from the center of the machine to the end of the boom. The entire weight is 147 tons. A 2-yard dipper is used, which, in operation, is usually filled full, and sometimes carries 4 yards at a load. The engine is of 50-horsepower capacity, though the boiler is rated for 54 horsepower. The runner considered the machinery strong enough for the use of a $3\frac{1}{2}$-yard dipper. This machine easily excavated earth 90 feet from the center of the machine on one side and deposited it 100 feet from the center on the other side. At the time the machine was visited it was digging a channel 25 feet deep and depositing the material on a waste bank between 15 and 25 feet high without difficulty. The following table indicates the cost of operating this machine for the season of 1908, and gives the cost per yard of excavation:

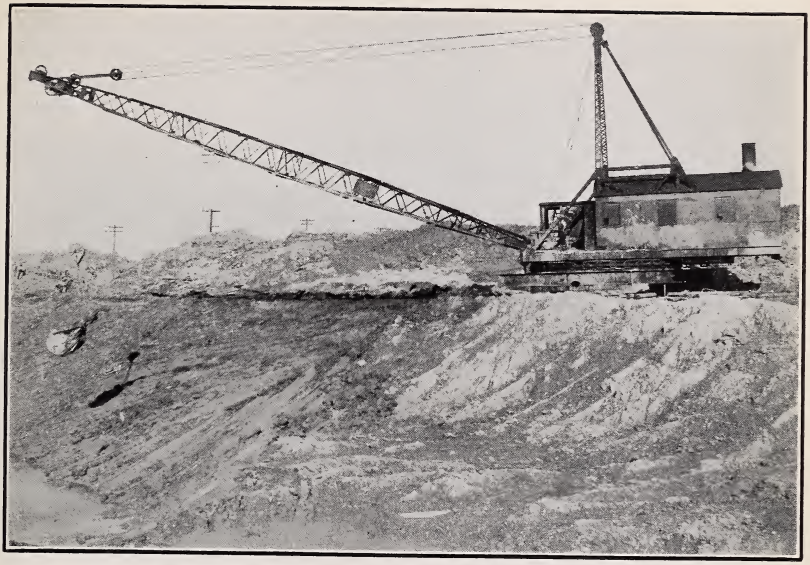


FIG. 1.—DRAG-SCRAPER EXCAVATOR USED ON NEW YORK BARGE CANAL.

FIG. 2.—HYDRAULIC SUCTION DREDGE, SHOWING DISCHARGE PIPE SUPPORTED BY CANTILEVER.

Drag scraper machine at work on New York Barge Canal.

Item.	April.	May.	June.	July.	August.
Fitting up	$426.80				
Excavation	$319.74	$684.29	$747.77	$850.69	$1,118.57
Repairs		$15.82	$62.60	$48.23	$75.12
Interest and depreciation, 21 per cent	$175.00	$175.00	$175.00	$175.00	$175.00
Shifting on work		(a)		$77.02	
Total for month	$921.54	$875.11	$985.37	$1,150.94	$1,368.69
Average cost per yard	$0.177	$0.048	$0.0388	$0.0348	$0.0289
Yards completed during month	5,205	18,365	25,333	33,055	47,363

[a] Machine fell into canal.

Average cost for the season, including all charges, 4.1 cents per yard.

In May the items of cost of operation were as follows:

Engineer, at $90 per month	$90.00
Engineer, at $95 per month	84.04
Firemen, pump men, watchmen, and laborers, at $1.75 per day	363.00
Coal, at $3 per ton	147.00
Repairs	15.82
Total	699.86

The first cost of this machine was $10,000.

It will be noted that the cost per yard for the season, including the expense of setting up the machine, with an estimate for interest and depreciation, amounts to 4.1 cents per yard. The excavation made during this season was in a cut 25 feet deep and about 100 feet wide on the bottom. The material was a stiff clay for the most part, but few, if any, stumps or bowlders were removed. The machine is moved forward on the work by means of cables. The cost of moving would have been reduced by an arrangement of gears attached to the axle. Similar machines are stated to excavate earth for levee building in Louisiana at a cost of 3 to 4 cents a yard. The United States Government is constructing levees near Greenville, Miss., by the use of one of these excavators. On a trial run of ten days it excavated at a cost of a little more than 2 cents a yard. Most of the work for which it is used, however, is in topping out old levees. Major Walker, of Memphis, states that in doing this work the machine will excavate about half as much earth as when making a new cut and building an entirely new levee. On the work for which he had estimates, the cost for the entire camp, as near as he could determine, in excavating earth, topping out the levees, and putting them in condition for seeding, was between 7 and 8 cents a cubic yard.

Another type of drag-scraper excavator is illustrated in Plate II, figure 1. The principal parts of this apparatus are a hoisting engine; a tower 65 feet high, guyed to cables extending to the ground on each side, where, instead of being stationary, they slide on other

cables stretched parallel to the ditch and fastened to deadmen, thus giving stability to the tower, while allowing it to move parallel to the ditch; the scraper bucket in which the earth is moved; and cables for operating the bucket. The machine is built upon a platform and is moved on rollers by winding a cable fastened at one end to a deadman. A more efficient provision for moving the machine would doubtless result in considerably reducing the cost of operation. A larger illustration of the bucket used with this machine is given in Plate II, figure 2. As is readily seen, this bucket is not as fully developed as are other types, but it has recently been improved. The entire machine as illustrated cost about $1,500. With the strengthening of parts necessary to fit it for extra-heavy work the cost would be about $2,000, of which $1,200 would represent the cost of a hoisting engine.

In operating the excavator the bucket is loaded by pulling it toward the tower by winding up the cable, which, passing over the lower sheave on the tower, is attached to the front end of the bucket. The bucket is then dumped by winding over the drum the cable which passes over the sheave on top of the tower and which is attached to the back end of the bucket. The bucket is returned to the ditch by further tightening the upper cable and loosening the lower one, when it quickly slides back by gravity to the starting point. The earth is deposited between the ditch and the machine.

The following is the cost for each eight-hour shift in operating this machine:

Engineer	$3.00
Fireman	2.00
Foreman	3.00
Signal man	2.00
Cable shifter	1.60
Horse and man, moving track	3.00
4 laborers, at $1.60 each	6.40
1½ tons of coal to the shift, at $3 per ton	4.50
Total	25.50

If to this is added $1.50 per shift for maintenance, depreciation, interest, and repairs at the rate of 50 per cent per annum on the original cost of the investment, the total cost per shift is $27.

By arranging for the operator to work from a station in the tower, where the work would be in full view, the signal man would be eliminated, and by placing the machine on a track with an arrangement for moving the machine ahead on the work by means of gearing attached to the axles probably two or three more men could be dispensed with, thus further reducing the cost.

The bucket used on this machine had a capacity of about 2 yards, but in ordinary operation at least 3 yards were carried at each load.

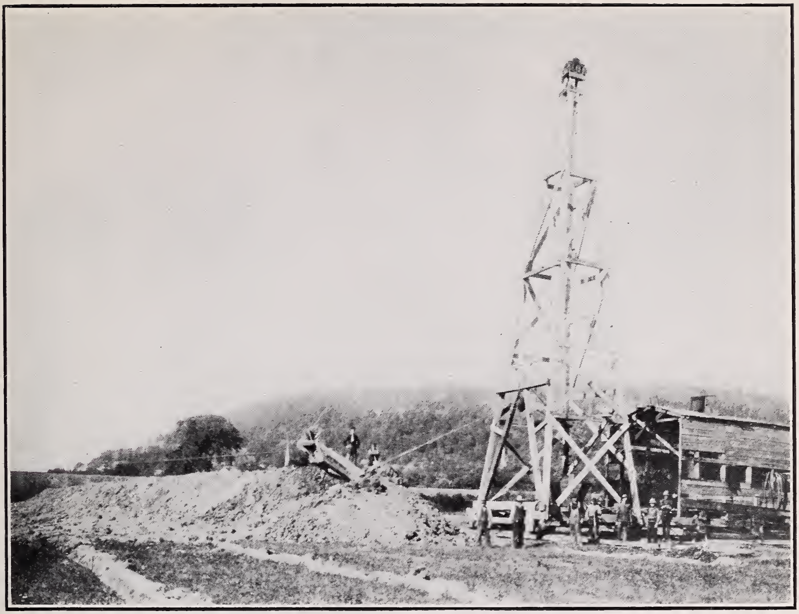


FIG. 1.—TOWER DRAG-SCRAPER EXCAVATOR.

FIG. 2.—BUCKET USED WITH TOWER DRAG-SCRAPER EXCAVATOR.

While in operation about 1 bucketful was excavated and deposited in each forty seconds. This would make a rate of 4 cubic yards a minute, and the contractor was of the opinion that he could maintain an output of 1,000 yards per eight-hour shift for an entire season's run on continuous work of a favorable character. The work actually done was not carried on continuously, and the best record made was 40,000 yards per month for two shifts for one machine.

At a cost of $50 a day for two shifts this would amount to about 3 cents per yard for the month's work.

The machine has a reach of 210 feet from the far side of the ditch to the near side of the waste bank. That is, all the dirt must be excavated and deposited in a space of 210 feet, making a waste bank about 20 feet high if necessary. The bucket is remarkably well under control.

This machine was in many ways crudely built, and its excellent record is due apparently to the exceedingly simple principle of its operation, and to the economy of power, motion, and time in excavating. The bucket moves on a straight line, across the excavation and onto the waste bank, and when dumped slides with great rapidity down the tightened cable to the position for digging.

With a construction including modern devices for moving on the work and the improved bucket, it seems that this should be a very important addition to the types of excavating machinery. It is fitted for digging ditches 20 to 100 feet wide and 2 to 30 feet deep, though its greatest economy of operation is in constructing the larger sections.

THE HYDRAULIC SUCTION DREDGE.

For the construction of the larger levees the use of the hydraulic suction dredge is entirely feasible in connection with the use of other excavating machines. Figure 2 illustrates sections of the proposed levees and ditches. By the construction of the muck ditch a retaining bank will be built to as great height as the earth can be made to stand. A similar retaining bank will be constructed at the other toe of the levee by depositing earth excavated from the nearest margin of the ditch. The space between these two retaining walls can then be filled by a hydraulic suction dredge, the discharge pipe being supported by a cantilever. This machine, Plate I, figure 2, in its present state of development probably represents the most economical method now in use for excavating very large channels, unless the ladder dredge be excepted.

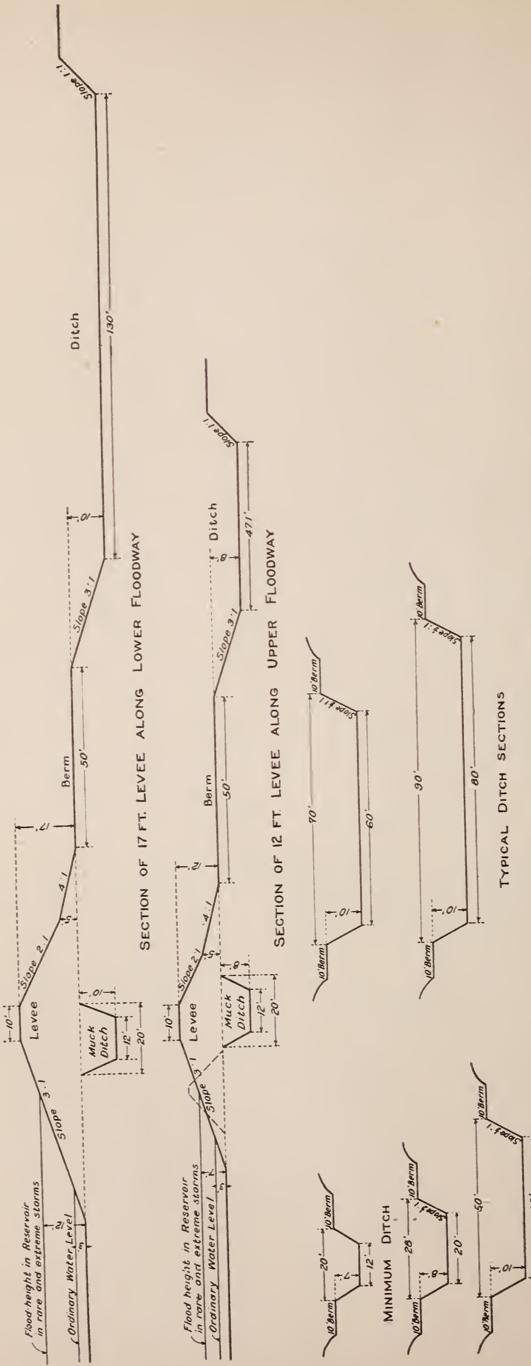


Fig. 2.—Representative sections of levees and ditches.

The following table indicates the cost of operating a hydraulic suction dredge on the New York Barge Canal in 1908. The dredge in question is of modern construction, has a 20-inch discharge pipe, and cost $115,000. A large part of the excavation was in stiff clay, though a part was in sand. The clay was of such firm texture that after remaining on the ground over winter the pieces had the same shape as when they were discharged from the end of the pipe line, still showing the marks of the cutter. While removing the old rock wall of the canal the dredge was stopped sometimes twenty times a day, it is said, for removing bowlders from the pump. Once during the season the dredge was sunk to the bottom of the canal. Otherwise the work was favorable, and the excavation made was representative of the capacity of the machine in ordinary clay soil. The charge against plant is intended to cover interest and depreciation at 15 per cent per annum. Under "Material" are included coal waste, tug hire, and similar items.

Cost of operation of hydraulic suction dredge on the New York Barge Canal for the season of 1908.

Item.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
Labor	$3,670.95	$5,169.29	$5,615.75	$5,835.14	$5,985,87	$4,993.11	$4,834.14
Plant	408.30	1,367.60	1,677.85	1,735.50	1,631.15	1,692.85	1,791 15
Material	1,900.62	2,558.88	2,263.16	2,446.45	2,320.92	2,430.05	2,573.50
Total for month	5,979.87	9,095.77	9,556.76	10,017.09	9,937.94	9,116.01	9,198.79
Yards excavated	120,673	204,838	203,474	207,520	174,395	231,473	214,438

Unit cost for the season, 4.63 cents per yard.

An examination was made of several suction dredges on the New York Barge Canal and of the material excavated by them. In only one instance was the material at all comparable with that to be excavated in building the floodway levees, and in that instance the material was being removed at a cost of about 2½ or 3 cents per cubic yard, including all cost of maintenance, depreciation, repair, and interest. The work planned for this type of machine on the St. Francis project is the excavation of large ditches outside the floodways, using the earth for constructing levees, and in dredging the channels of Tyronza and Little rivers. In the former case the work is estimated at 10 cents per cubic yard plus the cost of clearing and grubbing the ditch section at $150 per acre. In the second instance the work is estimated at 9 cents per yard, including the cost of clearing banks to enable the material to be deposited. This dredge can be used to advantage also for constructing two or three of the largest lateral ditches, which empty into ditches along the floodway.

OTHER TYPES OF EXCAVATORS.

It is very probable that in letting this work bids would be received from operators of machines of other types, such as the cantilever-crane excavator, the ladder dredge, and endless-chain levee building machines. In designing the ditches extended investigations were made of machines actually in use, and every construction is planned as well within the limits of economical operation of one or more of the machines described.

The purpose in discussing the construction methods and cost, excavating machinery, and similar topics before taking up the plan is to take account of the fact that the latter is largely dependent upon the way in which the work must be carried on in order to insure economy of operation, and also to facilitate the adapting of the work to the available types of excavating machinery.

BASIS OF ESTIMATES.

The estimate of cost of excavation was made by determining as nearly as possible the actual cost to the contractor of similar work and by placing the estimate at about twice the approximate actual cost.

An estimate of $150 per acre is considered sufficient for clearing the right of way of the ditch preliminary to using any of these machines. Two of the drag-scraper machines first described, following each other, would be sufficient for building the largest of the levees planned on this project. By working upstream sufficient drainage would be secured for their successful operation, and the levee is planned of such section that there would be no doubt about the material remaining in place. In addition to the cost of clearing the right of way and grubbing the ditch section it is estimated that 9 cents per yard is sufficient for excavating the earth and building the smaller levees, and that 10 cents per yard in addition to such clearing and grubbing is sufficient in case of the larger ones.

The cost per yard of building levees usually includes the digging of a muck ditch and grubbing the levee base. This method is replaced in the present plan by the construction of a very large muck ditch by means of a dredge, the cost of which is estimated in addition to building the levees. This change would amount to an addition of between 1 and 2 cents a yard if the work had been calculated in the usual manner. If the entire cost of digging muck ditches and clearing right of way is considered as a part of the cost of building the levee section, the estimate amounts to between 12 and 13 cents per cubic yard. In addition the levees are made of large section, and the yardage may be measured in the excavation instead of in the fill, as is usually the case. As 10 per cent shrinkage is usually provided for, this would make an additional difference of about one-half cent per yard.

The greater part of the Mississippi levees were constructed years ago, when levee-building machinery was not well developed. Many of the jobs let now are for topping out old levees or for building short loops. Quite commonly the separate jobs are not large enough to justify the installation of expensive equipment, and often must be done on short notice when there is not time to install such equipment.

Specifications for levee work nearly always prevent a continuous borrow pit, require a very wide berm, and impose other conditions which make the use of levee-building machinery impossible. The very different conditions under which these levees will be built and the difference in conditions after they are built make unnecessary some of the requirements usually made in levee construction. Some of these favorable conditions are shorter duration of floods against the levees, with correspondingly small seepage, and a perfectly unbroken ground surface in the floodways, with an exceedingly large and deep muck ditch, which also reduces the seepage.

It is seldom that a large piece of levee construction is let in which conditions for the operation of a single type of machine are so uniformly favorable. The estimate on this work is not made as applicable to usual jobs of levee construction.

ACQUIRING RIGHT OF WAY.

The right of way for the reservoirs and floodways includes the lowest and most worthless land in the district, and a great part of that included in the St. Francis Reservoir is held to be unsurveyed government land.

The land occupied by the lateral-ditch system varies in quality, but would represent the average of land in the district. It is believed that the entire land to be used for right of way can be secured for not more than $20 an acre on the average, and probably for less than that amount. The estimated cost of right of way is about 10 per cent of the entire estimated cost of the system. It has not been the custom heretofore in this region to allow damages for the use of right of way in establishing drainage systems; yet it seems that this is the only equitable method to pursue, and is desirable, moreover, because for purposes of maintenance, the drainage district should own and control the land occupied by the ditches and waste banks.

HYDRAULIC PROBLEMS AND COEFFICIENTS.

THE USE OF KUTTER'S FORMULA.

In computing the velocities of water in the floodways and drainage channels, Kutter's formula has been used in all cases except for the lower parts of Tyronza River and the St. Francis River, where

the channel is crooked and the surface slope very small. For all artificial channels with regular sections and long tangents, a roughness coefficient "N" of 0.025 has been used. As with a very few exceptions none of the channels are more than 10 feet deep, it is probable that, especially in the larger ditches, serious irregularities of sections due to caving banks will not occur. The existing ditches within the district have remained in fairly good order for several years without maintenance. For the existing channels of Right-Hand Chute and Tyronza River, which are to be cleaned out, a roughness factor of 0.03 is assumed. While these channels will be given nearly uniform cross sections, the fact that they are not perfectly straight and that they will have a greater depth than 10 feet will probably result in the formation of sand bars, causing the channel to take an irregular section, and consequently to have a lower velocity.

Velocities in the St. Francis and Little River floodways were calculated by using a roughness factor "N" of 0.03. These floodways will have exceptionally uniform sections, the only serious obstruction to flow being the vegetable growths which may occur. The prevention of these growths is discussed under the subject of maintenance.

In order that the high-water surface in the St. Francis River at Marked Tree may be low enough to furnish drainage for tributary areas, it is necessary to maintain a very flat slope in the river in times of flood flow from this point to the lower end of the St. Francis flood way. On applying Kutter's formula to determine this slope with the water level in the river at Parkin at 212 feet above sea level, and with a flow of 2,000 second-feet in the channel and using a roughness factor "N" of 0.03, a surface slope of only 0.02 foot to the mile is indicated. It is evident that in a very crooked channel, of continually varying shape and section, the loss of head in turning bends, in conforming to changes of cross section, and in the internal resistances of the water, would result in a surface slope greater than that found by the use of this formula. The only data at hand to indicate what would be the loss of head under these conditions are those contained in Humphrey and Abbott's work on the Hydraulics of the Mississippi River. As a rough approximation it may be said that this formula indicates a loss of 70 to 100 per cent of the velocity head for each 90° of curvature around bends. No close estimate of the loss of head due to bends and irregularities in the St. Francis channel can be made from data on hand; but where the use of Kutter's formula indicated a surface slope of 0.02 foot to the mile a slope of 0.1 was used instead, it being assumed that the irregularities of the channel would not require more than five times as great head as that indicated by the formula. That this assumption is conservative is indicated by the fact that in January, 1907, when the St. Francis River at Marked Tree was at the highest stage ever recorded when not affected by Mississippi overflows, and when several times as

much water was flowing in the channel as will be carried after the construction of the floodways, the slope of the water surface between Marked Tree and Parkin was only 0.2 foot to the mile. Using Kutter's formula and assuming a roughness factor "N" of 0.03, a velocity of about 3.5 feet per second is indicated by a slope of 0.2 feet per mile in this channel. Considering the relation of slope to velocity and the fact that in this system the water in the St. Francis channel at extreme flood stage will not require a velocity of more than 0.75 foot per second, it is seen that the slope will doubtless be less than the 0.1 of a foot here assumed.

LIMITATION OF VELOCITIES.

In considering velocities which are desirable in drainage channels it is assumed that in long straight channels of uniform slope, depth, and cross section higher velocities may be allowed than in crooked streams of varying section and slope. In improving the two natural channels, Tyronza River and the Right-Hand Chute of Little River, uniform bottom slopes are planned, though the velocity and surface slope will vary with the natural enlargements of the channels. In these streams, where a slope of 6 inches to the mile is calculated, the maximum depth of water will be about 8 feet and the velocity at flood stage about 2 feet per second. In artificial channels with uniform slope and section and long tangents no velocities in excess of about 4 feet per second are planned. It is believed that under these conditions this velocity, occurring only in time of extreme flood, will not cause extensive erosion or scouring, and will not form bars in the channels to a serious extent. It is estimated that extreme velocities within the floodways will not exceed about 2½ feet per second, and that the usual rate of flow will be about half this amount. As the floodways consist of long straight reaches of uniform section it is believed that these velocities will cause no damage to the levee system.

In fact, the difficulty with the whole drainage system is not to prevent high velocities, which would scour, but rather to secure a rapidity of flow sufficient for the maintenance of the ditch. The minimum flood velocities which are planned are about 1 foot per second, but in time of low water the flow in many instances will be much slower than this. Higher velocities than are desired will be developed by the drop-off curve at the lower end of the St. Francis floodway, unless a dam is constructed across the lower end. As the construction of a power plant would solve this problem it is not dealt with in this report. The chief damage resulting from this increased velocity would be the enlargement of the channel of Big Bay within the floodway, thus making more expensive the construction of a dam for power if it were done at a later time.

SEEPAGE.

The question of seepage through or under the Mississippi levees into the district is an unimportant one in considering the district as a whole, for the amount of water which collects on a given surface in any one day is so small as compared with the amounts which must be removed in time of heavy rain as to be nearly negligible. Seepage affects the land because of a steady accumulation at a constant rate for considerable periods, even though the amount which collects during any one day is not large.

The conditions will tend to cause less seepage from the proposed floodways than from the Mississippi River. The land at some distance from the Mississippi River is usually lower than the river banks, whereas that at an equal distance from the floodway is usually higher. The floodway levees are planned to have muck ditches 10 feet deep filled with impervious material, whereas the muck ditches of the Mississippi levees are usually much shallower, and commonly are filled with light surface soil. Outside of the levee will be a ditch 10 feet deep to intercept seepage and to relieve the static head of water in the ground. In case of the Mississippi the river bank is usually a nearly vertical wall in which all sand strata to a considerable depth are directly exposed to the water, and water from the river can directly enter all permeable layers. It has sometimes been noted in levee construction that a silting over of the bottoms of borrow pits, rendering them less permeable, has decreased the seepage on the land side of the levee. In the proposed floodways the ground surface between the levees will remain unbroken, and seepage water before it can pass horizontally beyond the limits of the ditches outside the levees must sink more than 10 feet into the soil. Even small amounts of silt deposited in the floodway will tend to make the surface more and more impervious, and so will tend to prevent seepage.

It is believed that conditions which cause seepage along the Mississippi behind the levees will not be reproduced here. In case a small amount of seepage does occur, it can be relieved by drainage into the ditches outside the floodways. Its occurrence, even to a considerable extent, would be one of the minor difficulties to be handled in perfecting what is the only effective way of handling the vast quantities of water which must be carried through the district.

THE STAGE OF WATER IN THE ST. FRANCIS RIVER AT THE OUTLET OF BIG BAY.

The plans for this district are based upon an estimate that the water level in the St. Francis River at the outlet of Big Bay will not reach a greater elevation than 212 feet above sea level in time of

greatest flood. During the past fifteen years this elevation has been exceeded five times at the Iron Mountain Railroad bridge, 15 miles upstream from this point; but four times out of the five the high water was that which had entered the district from the Mississippi by overtopping the Mississippi levees, and was finding its way back through the St. Francis River. As the plans for this district presuppose the success of the Mississippi levee system, it will not be necessary to consider these occurrences. The remaining case is that of January 15 to 19, 1907, when the St. Francis River at the Iron Mountain Railroad bridge, 15 miles above the outlet of Big Bay, had an elevation of 213.4 feet. As the St. Francis River at this time had a fall of 0.2 foot to the mile from Marked Tree to this bridge, and also from the bridge to its outlet into the Mississippi, the high-water line at the outlet of Big Bay must have been about 3 feet lower than the 213.5 recorded at the bridge, or about 210.5 feet.

A discussion of the conditions causing this flood will indicate the possibility of a recurrence of an equal stage in the future. The rainfall for September and October, 1906, had been greater than the normal amount for those months, but this excess had not appreciably affected the stages of streams. November was a month of exceptionally heavy rainfall over a large area, a precipitation of 10.9 inches in five days being recorded at Marked Tree. While there was no flood recorded in November on the gauge at the Iron Mountain Railway bridge mentioned above, the water level rose gradually from 191 feet to 202 feet during the month. In December the precipitation was generally above the average, and the elevation of the water surface at the gauge rose to 206 feet by the end of the month. By this time all the storage capacity of the upper St. Francis Valley had been used. Not only was the ground entirely filled with water, but water stood over the surface of the lowlands from one to several feet deep all the way from the Ozark Mountains in Missouri to the point under consideration, and all river channels were full. With these conditions existing at the beginning of January, 1907, a general rain on the 2d and 3d of January fell over the entire watershed, with a precipitation in the two days of 1 to 7 inches, varying in the different localities.

The rainfall for the nine days from December 27 to January 4 amounted to more than 6 inches on the average over the entire watershed of about 7,400 square miles. An extreme flood stage of the streams followed, culminating on January 15 to 20, during which period the gauge at the Iron Mountain Railway bridge recorded the elevation of 213.4 feet. The flood level remained within a few inches of this stage for about twenty days, during which time there was an additional rainfall of 1 to 4 inches, and it was not until the middle of April that the stream reached a lower level than that of ordinary

high water (200 feet). Assuming that one-half of the total precipitation of about 11 inches for the twenty days from December 14 to January 3 was discharged through the outlet in the same number of days, we would have a run-off of about 50,000 cubic feet per second. In this connection it may be noted that the St. Francis River at the outlet of Big Bay has a cross section of 17,500 square feet up to an elevation of 212, a hydraulic radius of 27, and at this time had a surface slope of about 0.2 foot per mile. Estimating the discharge by Kutter's formula, using a roughness factor of 0.03, we find the discharge to be more than 60,000 second-feet.

As this is the greatest recorded flood at this point, unaffected by Mississippi overflow, it may be assumed that a system which would care for this flood at the outlet would be sufficient in that regard for all conditions. It may then be asked what stage such a storm would produce after the completion of the proposed system. The discussion of run-off will not be repeated here, but the following factors may be mentioned as affecting the situation:

(1) The discharge from the mountainous regions of the upper St. Francis River in Missouri, about 1,500 square miles, being confined to a channel and thus prevented from dissipating its waters in the lowlands, will tend to cause higher stages, though floods on this stream will be modified in filling the stream channel for about 130 miles after leaving the mountains, and in passing through the St. Francis Reservoir. The waters of the St. Francis River which now overflow and pass into Black River will doubtless within a few years be restrained by levees, and will enter this district.

(2) One thousand five hundred square miles of mountain run-off from the upper Little River watershed in Missouri is to be diverted into the Mississippi River at Cape Girardeau, thus relieving this district.

(3) The soil of the St. Francis Valley, except along Crowleys Ridge, when well drained, will absorb the water of the heaviest rain, allowing it to flow off gradually without producing extreme flood conditions.

Considering these factors it will be recognized that the stage of water at the outlet of Big Bay will depend almost entirely upon the quantity of water which reaches this point from the Ozark Mountains in Missouri through the St. Francis floodway. The total amount of water which it is estimated the floodway will have to carry under the most extreme conditions of flood flow is about 75,000 second-feet. To this may be added about 10,000 second-feet from other sources, which would be the greatest amount that will reach this point through the St. Francis River and other channels, making about 85,000 second-feet in all to be carried in the time of greatest flood. Such a flow will probably occur at most but once or twice in a generation and probably will never be approximated. If it should occur the water

would perhaps rise to a greater height than 212 feet at the outlet of Big Bay.

It is probable that these estimates are very considerably in error. The capacity of the St. Francis River, as found by determining the slope and applying Kutter's formula, might seem to lead to roughly correct conclusions, but with slopes so flat, and with channels so irregular and crooked as those of the St. Francis, it is probable that the head required in overcoming internal resistances and in turning bends will be so large a factor in the flow as to set at naught all effort to apply this formula. Dependable estimates of the capacity of the St. Francis at the mouth of Big Bay can be made only after a series of careful gaugings of the stream have been made during high water. The financial limitations of this survey prevented such gaugings being made. For all ordinary floods the storage supplied by the St. Francis reservoir would so modify the flow as to prevent a high stage below the mouth of the floodway, and if the improvement for power is made, as previously suggested, this regulation would be complete, except in the most severe storms, occurring at intervals of several years. The action of the St. Francis reservoir, modifying as it will the floods from three-quarters of the drainage area, and the slower run-off which will occur from well-drained soil, are the factors counted on to modify flood conditions at the mouth of the floodway, and farther south in the St. Francis River.

It is noticeable in examining the record of gaugings at the Iron Mountain Railway bridge that while stages of 212 feet or more have occurred five times in fifteen years (four times as the result of Mississippi overflows above when great quantities of Mississippi River water flowed through the district), only once has a stage of more than 215 feet been exceeded, and only twice has the stage reached 214 feet. It seems that upon reaching the stage of 212 feet, an additional rise results in so great increase of cross section and surface slope below, that a large additional discharge does not greatly increase the stage. A stage of 215 feet at the bridge would indicate perhaps 212 or 213 feet at the outlet of Big Bay. An examination of old high-water marks at the latter point indicated 212.5 feet as about the highest of these.

It may be safely assumed, therefore, that under all but the most extraordinary conditions following the construction of the proposed system, stages in excess of 213 feet would not occur; and should even these stages occur, they would last but a short time.

Extreme high water at the outlet of Big Bay can result only from torrential rains in the Ozark Mountains in Missouri, discharging through the St. Francis floodway, and it is improbable that a maximum discharge through the floodway would happen at the same time as the maximum discharge through the ditch system. If these maximum discharges did not coincide, and only a moderate stage of water were flowing in the drainage ditches and in the old channel of

the St. Francis River, the maximum discharge through the floodway into the St. Francis River, at the outlet of Big Bay, would have a ponding effect in these drainage outlets, which would not extend very far upstream.

However, to provide against contingencies, the ditches along the south line of Poinsett County and at the south extremity of St. Francis Lake will be built with solid waste banks through which flood gates will be constructed. Then in event flood water should cause the drainage ditches to overflow, the flood gates would be closed for a few days until the water in the ditches had receded. It is anticipated that a well-drained soil might be shut off from a drainage outlet for a

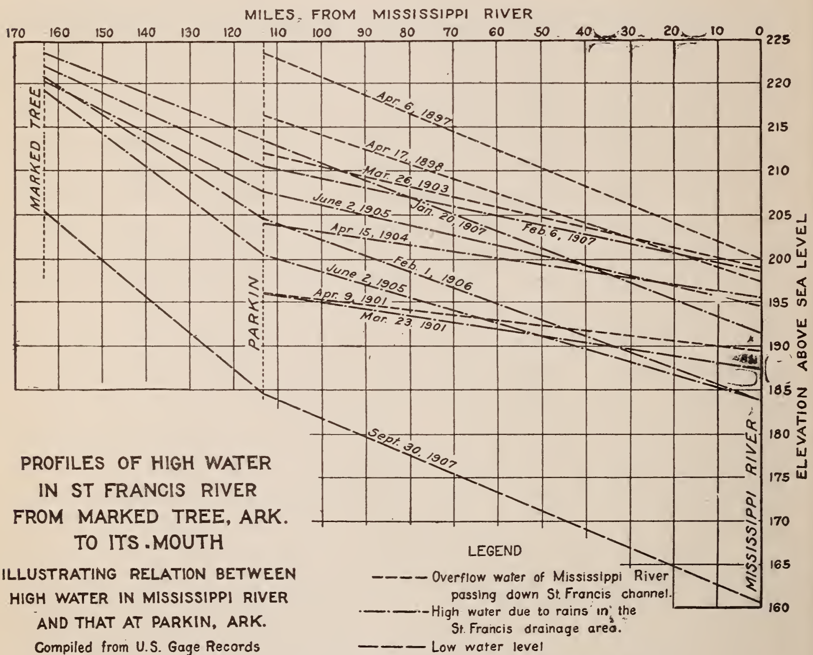


FIG. 3.—Profiles of high water in St. Francis River below Marked Tree, Ark.

few days without great loss. The only part of the district not entirely protected in this way is a small area at the head of Fortune Slough in the south part of Poinsett County and west of the St. Francis River. When it is considered that only a small area in the lowest part of the district would, under any conditions, require even the use of these levees, it may be seen that the success of the district is in no way imperiled by conditions at the outlet.

A careful comparison of the stages of the Mississippi at Helena, near the outlet of the St. Francis River, with those of the St. Francis at the bridge near Parkin above described (fig. 3) indicate that with a stage of 212 feet at the latter place the discharge would not be affected

by the stage at Helena, even should high stage at the two points occur simultaneously, which is very improbable. No record exists of a coincidence of high water at Helena with high water at Parkin except when the latter was caused by a failure of the levee system above. Even in these cases, the increased cross section of the lower St. Francis due to high water in the Mississippi has in all but one instance resulted in a very flat slope, amounting to only 10 to 12 feet between the Big Bay outlet and Helena. As extreme high water at Helena is 200 feet, it is seen that this will have no effect on a stage of 212 feet at the Big Bay outlet, when no Mississippi overflow is to be cared for.

The profiles of high-water lines in the St. Francis River during extreme storms (fig. 3, p. 52) were constructed from records of stream gaugings at Marked Tree, at Parkin, and at the outlet of the St. Francis River. The line for March 26, 1903, while indicating a flood due to Mississippi overflow, illustrates to some extent the condition which would exist with high water in the Mississippi River and a flow in the St. Francis unaffected by Mississippi overflow. It is seen that the stage at Helena would not cause a greater elevation than 212 feet at Parkin and about 210 feet at the outlet of the floodway.

THE SURVEY.

The object of the survey was to secure sufficient information concerning the topographic and physical conditions of the district to serve as a basis for a general plan for drainage. In general the work consisted of running base line levels and lines of levels 2 miles apart across the district from east to west, and in locating and making cross sections of all streams and depressions. On account of insufficient funds for completing the survey the data are not complete for the eastern and western margins of the district. Conditions in the bed of St. Francis Lake were not determined as fully as was desired, and no gaugings of streams were made.

A base line of levels was run from Luxora north to Blytheville, on the St. Francis and San Francisco Railroad; thence west on the Jonesboro, Lake City and Eastern Railroad to Nettleton; thence southeasterly along the St. Louis and San Francisco Railroad to Big Creek, and north on the same road to Luxora. The circuit of about 120 miles closed within about 0.25 of a foot. Secondary base lines were run from Leachville south to Dague, from Big Lake south and east to Wilson, and south along the St. Francis River to Parkin. The detail level lines were practically all checked by closing on one another on the base lines. In several cases small errors were made which have not been corrected, and these are all noted in the list of bench marks. Bench marks were set at each half mile on the level

lines. As a rule these consist either of copper nails or of copper rivets 2 inches long set in notches in the roots of trees, the trunk being blazed and marked by a timber scribe with the letter assigned to the instrument man setting the bench mark, and with its number. For instance, the mark "F-153" cut on the face of the tree indicates that the bench mark is No. 153 in the series set by Fairley. In Part II of this report the bench marks are listed according to the section, township, and range in which they are located, the number, location, elevation, and description being given, with a note indicating the amount by which the bench mark may be in error in case of those which were not satisfactorily checked. An examination of numerous stone and iron bench marks along the Mississippi River indicates that when they are set loosely in the ground, as is generally the case, their elevations change from year to year, and that they are not so permanently reliable as bench marks made in the roots of trees. It is believed that those made on this survey will prove to be a lasting benefit to the district in the future. Their destruction or removal is prohibited by statute.

All streams, bayous, and depressions of importance, except some of those along the eastern and western margins of the district, were located by traverse lines, and were cross sectioned at frequent intervals to determine their capacity and condition. All measurements were made by stadia, courses being taken by compass bearings.

It was not the object of this survey to locate land lines, and bench marks set at corners are not to be used for determining locations, as the locations are only approximate.

THE PLAN.

SUMMARY OF THE PROPOSED PLAN.

The plan includes:

(1) Provision for carrying through this district the water discharged from more than 4,000 square miles in Missouri and from Clay and Greene counties in Arkansas, 1,500 square miles of which are hilly or mountainous territory. (See fig. 1, p. 8.)

(2) Provision for main drainage channels to carry the drainage water from more than 1,500 square miles within the district.

(3) Provision for a complete system of detail drainage.

(4) Adjustment of the plans to the possible requirements of navigation, power development, and other interests.

The proposed reclamation works may be outlined briefly as follows: A floodway between dikes to carry the water of the St. Francis River is planned to extend from the north line of Craighead County southerly along St. Francis Lake to its south end; thence southwesterly to Big

Bay and down Big Bay to the enlarged channel near its mouth. A branch floodway similarly constructed to carry the waters of Little River is planned to begin at the state line and to extend southerly along Big Lake, and thence in a general southwesterly direction to the St. Francis floodway. The bed of St. Francis Lake will form a regulating reservoir, making possible the use of a smaller floodway than would otherwise be practical. In excavating earth for building the floodway levees, large ditches will be constructed outside the floodways, which will be used to their full capacity for carrying the drainage water from the adjacent land. The channels of St. Francis and Tyronza rivers and Little River, being thus relieved from the flood waters of Missouri, will be improved sufficiently to carry the remainder of the waters of the district. A system of lateral ditches averaging 1 mile apart will furnish thorough drainage for every part of the area.

THE FLOODWAYS.

Beginning at the state line on the east side and at the north line of Craighead County on the west side, levees are planned on each side of St. Francis Lake to confine the waters of the river within the lake bed. Ditches will be constructed east and west along the northern boundary of the district to collect all waters coming from the north and to lead them into the floodway. The waste banks will be deposited on the south side of the ditches, forming levees to protect the lands of the district from overflow around the upper end of the floodway levees. (See fig. 8, p. 58.)

For about 18 miles south from the state line the flow of the river through the lake bed will not be impeded, neither will its surface be raised to any great extent. For the lower 12 or 14 miles the lake bed will act as a storage reservoir, moderating through the lower floodway the flow resulting from storms in the mountainous region of the Upper St. Francis River. By the use of this reservoir the lower floodway may be made narrower than would otherwise be required. The lands of the St. Francis Lake bed, included in this reservoir and upper floodway, are for the most part either in the permanent lake bed or so low as to be reclaimed only with difficulty.

From the lower end of St. Francis Lake the floodway is planned to extend southwesterly to Big Bay and down that stream to its enlargement a few miles above its mouth. The floodway will be about half a mile wide, carrying water 8 to 12 feet deep in extreme flood, which will have a surface slope of about 4 inches to the mile. Ditches outside the floodway will be formed by the excavation made by building the levees, and these will be employed to carry the local drainage water of the district.

A branch floodway, similarly constructed, is planned to begin at the state line and extend southerly along Big Lake and thence southwesterly to its junction with the St. Francis floodway.

West of St. Francis Lake, in the northern part of Craighead County, a considerable area of land within the district will be drained into the floodway. This will be done by digging a ditch outside the floodway levee and preventing it from overflowing by a secondary levee until its water can be brought to the same elevation as that inside the floodway; the inside levee will then be discontinued and the water discharged into the floodway, where it can be carried almost without additional cost. By this plan the cost will be perhaps $200,000 less than if ditches were constructed to carry this water below the ground surface the entire length of the district. In the same manner the drainage of the area between the St. Francis and Little River floodways is discharged into the St. Francis floodway, except that of a few square miles just above the junction, which must be carried under the Little River floodway by means of an underground conduit. The northeastern corner of Mississippi County also can be drained effectively into the Little River floodway.

A ditch running east and west along the state line will divert all the remaining water from Missouri into the two floodways except that from perhaps a hundred square miles near Big Lake, which must be carried underneath these ditches and their adjoining levees and discharged into the ditches outside the floodways. By this plan Missouri land will not be damaged in any way, but, on the contrary, will be benefited by the Arkansas improvement.

MAIN CHANNELS FOR CARRYING THE WATERS OF THE DISTRICT.

The drainage waters of the district which are not carried into the floodways will be removed by the channels of Tyronza River, the two chutes of Little River, and the St. Francis River, and by the large ditches outside the floodways. Of the local drainage waters approximately a third will be carried in the improved natural channels, about a third in the ditches outside the floodways, and the remainder by the floodways.

This plan may be adopted at present, and the construction of the various parts be carried out from time to time as demand arises for the development of different localities; the construction of the floodway system, however, being necessary to the further development of a large part of the area.

The carrying out of this plan will result in the complete reclamation of practically every acre of land, except that occupied by the drainage works, within the district in Mississippi, Craighead, and Poinsett counties, and will benefit large areas in Cross and Crittenden counties.

POSSIBLE METHODS OF DISPOSING OF WATER FROM MISSOURI.

I. CONTROLLING THE BLACK, CACHE, AND ST. FRANCIS RIVERS TOGETHER.

It would be entirely feasible from an engineering standpoint to gather the waters of Black River, including Current River, with those of Cache and St. Francis rivers, into a single floodway near the Arkansas-Missouri state line, and to conduct them through the valley of Cache and White rivers, discharging into White River near its mouth. This improvement would require somewhat more than 100 miles of floodway, and would cost perhaps $5,000,000. It would relieve flood conditions throughout the entire length of the St. Francis, Black, and Cache rivers, and would probably give entire relief from overflows on White River, except within the region of influence of backwater from the Mississippi River. The construction of this system would reduce by perhaps $1,500,000 the cost of the work remaining to be done in the proposed district, and would relieve the lower course of the St. Francis River. Much of the possibility of water-power development elsewhere discussed would, however, be removed by this method.

A careful comparison was not made of the relative advantage of this plan over the one proposed, because of the improbability of so large a project ever being carried out under the existing conditions.

II. THE DIVERSION OF THE WATERS OF THE ST. FRANCIS RIVER IN MISSOURI INTO BLACK RIVER AND THENCE INTO WHITE RIVER.

This would only transfer the problem from one locality to another, and would be difficult of accomplishment in the face of opposition which would develop along White and Black rivers. It therefore does not merit further consideration.

III. IMPROVEMENT OF EXISTING CHANNELS.

The method toward which all previous efforts to improve conditions have been directed contemplates the improvement of the existing channels in such a manner as to give them sufficient capacity for carrying flood waters. In the light of the survey just completed, this plan is wholly impracticable, and would cost more than all the land in the proposed district is worth. For several reasons its impracticability has not been realized. It has been supposed that the flood discharge of the St. Francis River per unit of time after improvement would be about the same as at present, whereas it may be greater, for at present a great volume of the flood water of the streams of the valley flows into the lowlands of Missouri and Arkansas, which serve as storage reservoirs, allowing it to pass off very gradually. With the improvement of these streams and the confinement of their waters

to narrow channels, run-off conditions would be so changed as to set at naught all estimates based on their present flow. At present the flood discharge of these streams occurs when the lowlands are overflowed and when the water over the land in some parts of the district is 8 feet higher than it must be when the land is in good condition for cultivation. The capacities of the beds of these streams below the line at which the water must be carried are so small as to be wholly insufficient for carrying even the local drainage water of the spring months. In fact, the bottom of the Left-Hand Chute of Little River is so nearly at the same elevation as the adjoining land that it is only with difficulty that any important use can be made of this apparently large and commodious channel. It would be far less expensive in many cases to dig entirely new channels to carry the flood waters than to improve those already in existence sufficiently to serve the purpose required.

IV. THE PLAN RECOMMENDED.

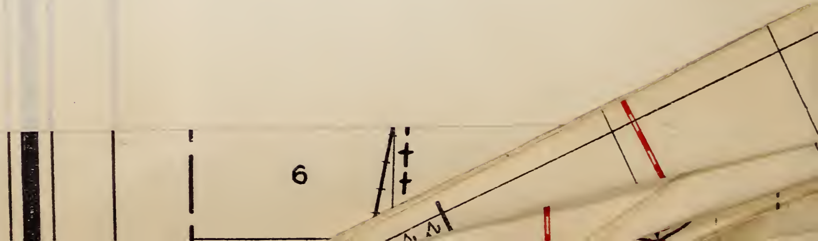
The method proposed in this report is the construction of floodways between levees, carrying the St. Francis and Little River waters above the surface of the ground, and for the most part outside of the channels they now occupy, leaving the latter to assist in carrying the local drainage water of the district. The cost of a wholly adequate system of floodways would be perhaps 20 per cent of the cost of improving the natural channels sufficiently to accomplish the same purpose, while at the same time with this method the natural channels would be preserved for other uses. The leveeing of the present channels of Little River and of the St. Francis River is not to be desired, because the banks of these streams are about 10 feet higher than the land on which the floodways are located. In some cases the ground surface along the floodways is lower than the beds of these streams. The water level between the dikes of the Little River floodway will be lower at flood stage than the ground level along either chute of that stream. For maps and profile of the district showing proposed improvements, see figures 4, 5, 6, 7, and 8.

In the plan adopted it is assumed that the hill waters of Little River will be diverted into the Mississippi River at Cape Girardeau. This course has definitely been decided on by the board of directors of the Little River, Missouri, drainage district.

THE FLOODWAY SYSTEM.

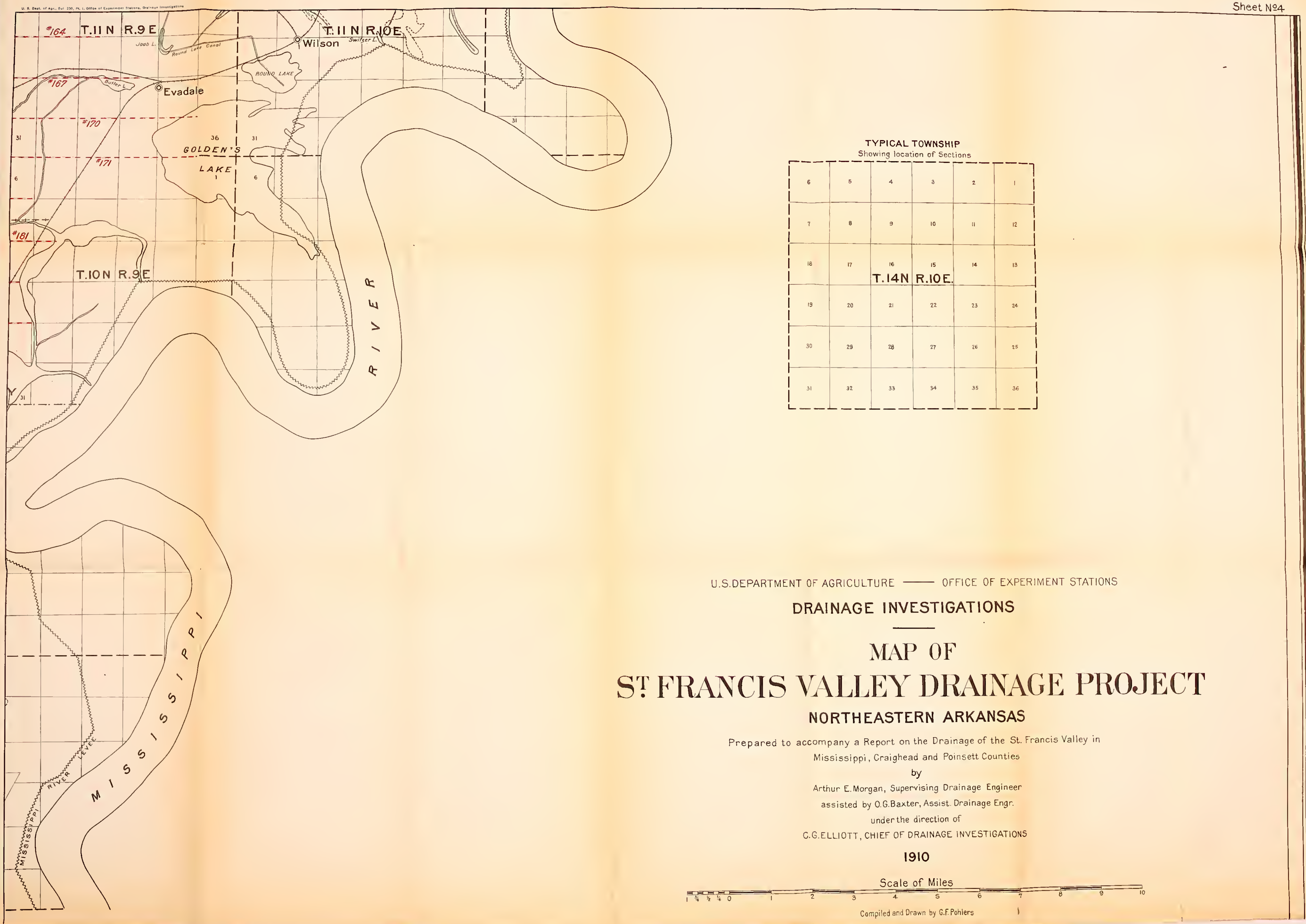
The St. Francis floodway will begin at the intersection of the St. Francis River channel with the north line of the district, and will extend south along the channel of the St. Francis River and Lake to the south end of the lake, thence southwesterly across a low area to Big Bay, and down the depression of Big Bay to a point near its outlet

St. Francis Valley Drainage Project, Ark.
U.S. Dept. of Agr., Office of Experiment Stations, Drainage Investigations


6

U. S. Dept. of Agr., Bul. 230, Pt. I, Office of Experiment Stations, Drainage Investigations

Sheet No. 4



U.S. DEPARTMENT OF AGRICULTURE —— OFFICE OF EXPERIMENT STATIONS

DRAINAGE INVESTIGATIONS

MAP OF
ST. FRANCIS VALLEY DRAINAGE PROJECT

NORTHEASTERN ARKANSAS

Prepared to accompany a Report on the Drainage of the St. Francis Valley in Mississippi, Craighead and Poinsett Counties

by

Arthur E. Morgan, Supervising Drainage Engineer

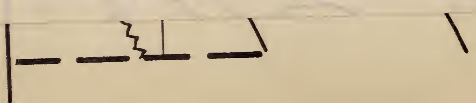
assisted by O.G. Baxter, Assist. Drainage Engr.

under the direction of

C.G. ELLIOTT, CHIEF OF DRAINAGE INVESTIGATIONS

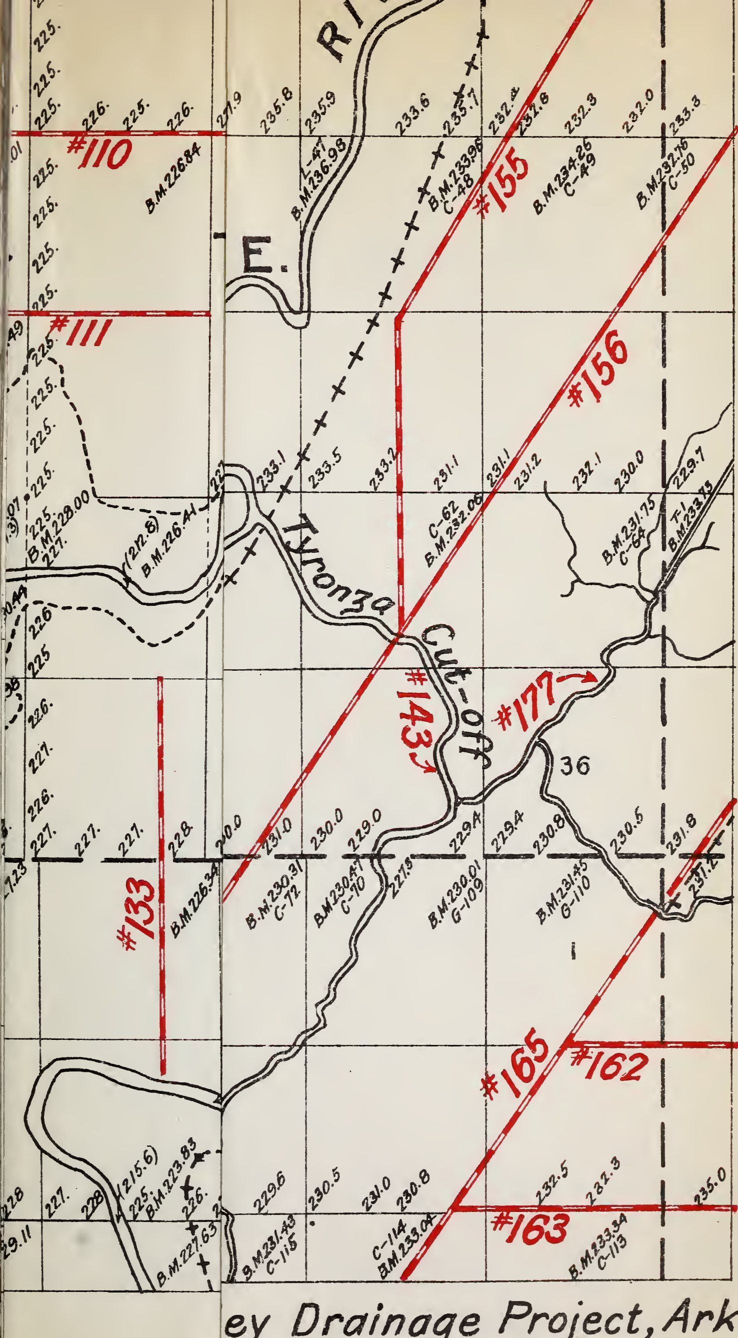
1910

Compiled and Drawn by G.F. Pohlers



St. Francis Valley Drainage Project, Ark.
U.S. Dept. of Agr., Office of Exp. Stations, Drainage Investigations

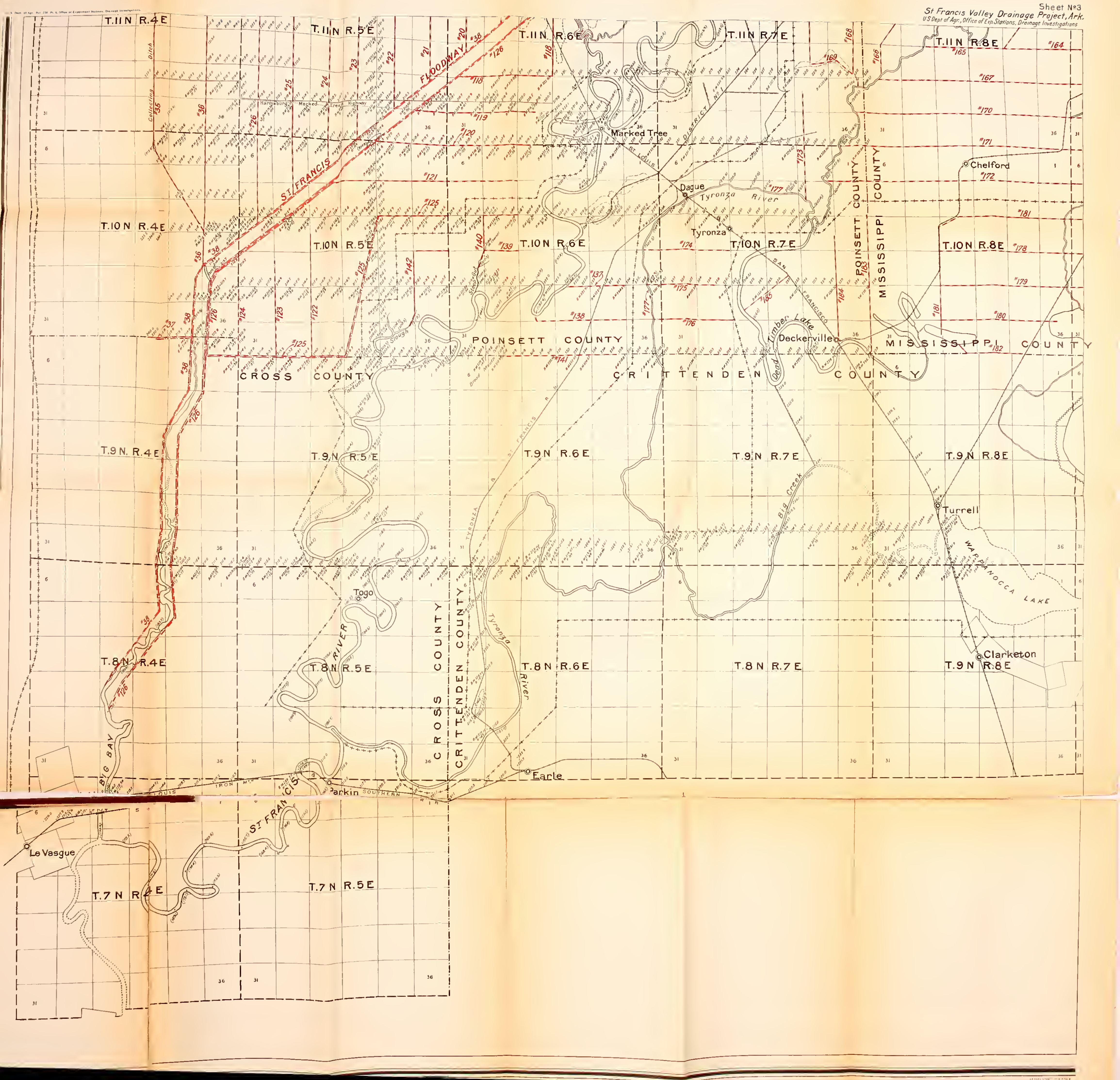
FIG. 5. MAP OF ST. FRANCIS VALLEY DRAINAGE PROJECT SHEET 2. NORTHEAST PART



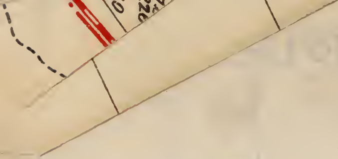
ey Drainage Project, Ark.

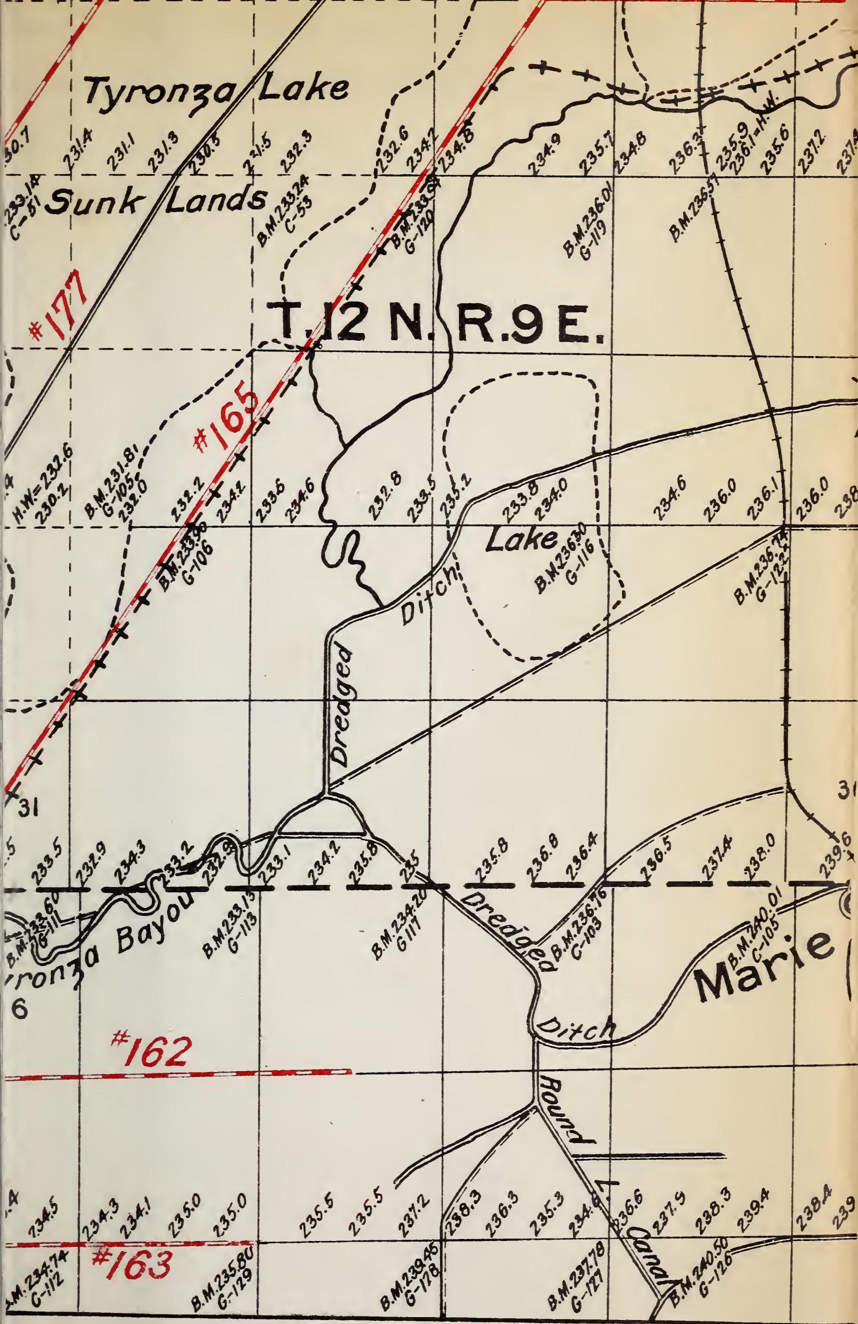
Exp. Stations, Drainage Investigations

THE NORRIS PETERS CO., WASHINGTON, D. C.



Sheet No3
St Francis Valley Drainage Project, Ark.
U.S. Dept. of Agr., Office of Exp. Stations, Drainage Investigations
T.11N R.4E
T.11N R.5E
T.11N R.6E
T.11N R.7E
T.11N R.8E
T.10N R.4E
T.10N R.5E
T.10N R.6E
T.10N R.7E
T.10N R.8E
T.9N R.4E
T.9N R.5E
T.9N R.6E
T.9N R.7E
T.9N R.8E
T.8N R.4E
T.8N R.5E
T.8N R.6E
T.8N R.7E
T.9N R.8E
T.7N R.4E
T.7N R.5E
FLOODWAY
ST FRANCIS
Marked Tree
Dague
Tyronza
Tyronza River
Chelford
Deckerville
Timber Lake
Dead
Big Creek
Turrell
Wappanocca Lake
Clarketon
Togo
Earle
Parkin
Le Vasgue
Big Bay
Collecting Ditch
Harrisburg - Marked Tree Highway
POINSETT COUNTY
MISSISSIPPI COUNTY
CROSS COUNTY
CRITTENDEN COUNTY
Fortune
River





St. Francis Valley Drainage Project, Ark.

S. Dept of Agr., Office of Exp. Stations, Drainage Investigations.

NORRIS PETERS CO., WASHINGTON, D. C.

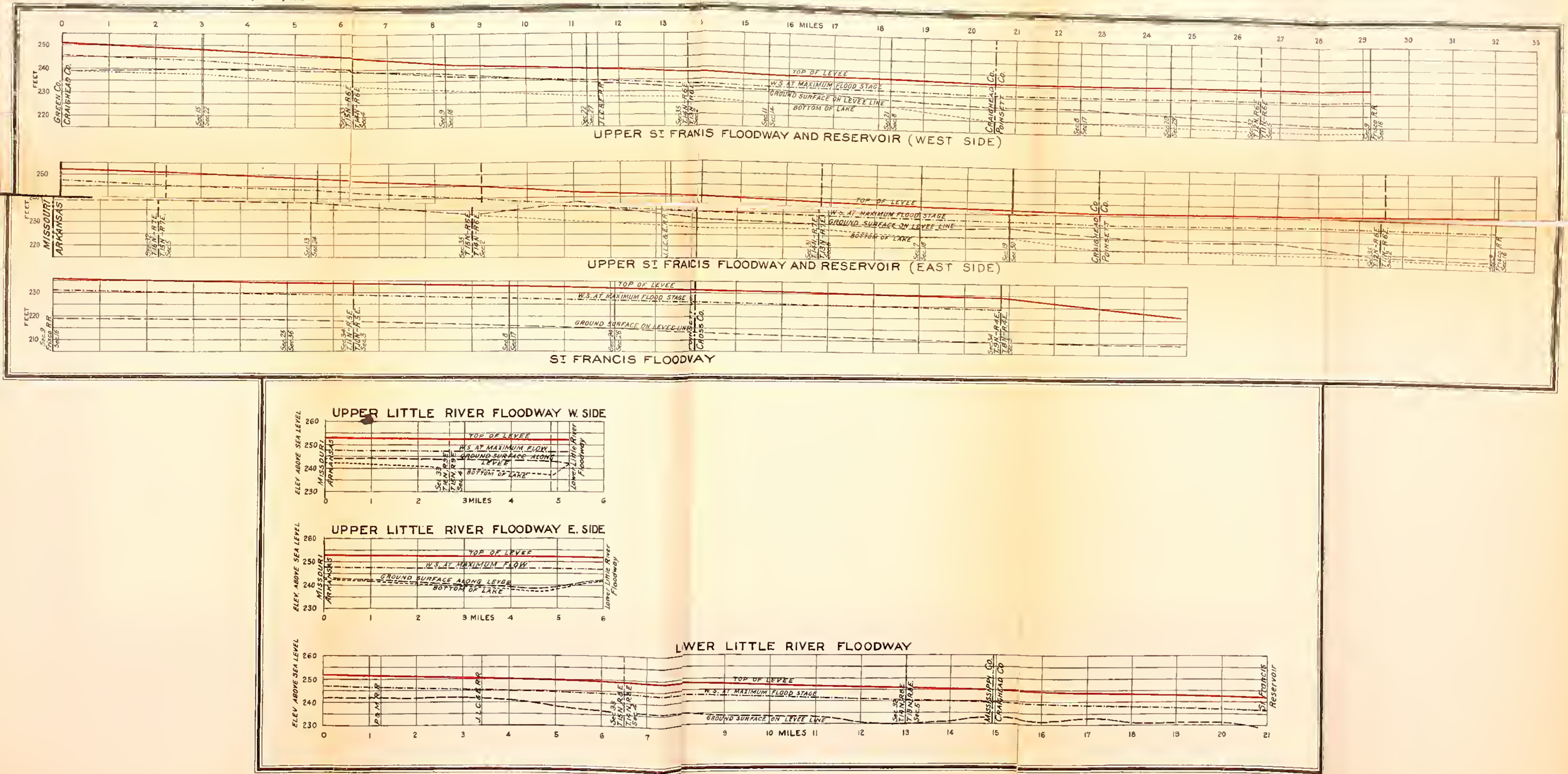


FIG. 8. PROFILES OF PROPOSED LEVEES FOR RESERVOIR AND FLOODWAYS.

Prop

------,

Exist

Ditch

Wate

Gove

Missi

Town

Secti

Coun

Railr

Surf

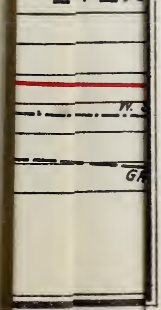
Eleva

Benc

Ditcl

THE NORRIS PETERS CO., WASHINGTON, D. C.

LVER



3. PRCES OF

into the St. Francis River. From this point the bay has a sufficient channel for carrying all water of flood flows. The floodway as planned will consist of two levees confining the water of the St. Francis River between them. An enlargement through the St. Francis Lake will form a reservoir, serving to moderate the flow of water in the lower floodway and in the St. Francis River farther south.

A discussion of the rate of inflow into the St. Francis River channel at the foot of the Ozark Mountains is included in the subject of run-off on page 32. The greatest average rainfall for ten days which has been recorded for the entire watershed, in May and June, 1893, was about 9.7 inches. As this plan provides for carrying off 9 inches from the entire mountain watershed in ten days, it is seen that it contemplates a rainfall perhaps 50 per cent greater than the greatest which has been recorded; for probably in a most extreme case not more than two-thirds or three-fourths of the rainfall of a ten-day period would run off during that time.

Between the foot of the Ozark Mountains and the upper end of the floodway is a channel 130 miles long, through which the flood flow must pass. At present a large part of the water entering the upper end of this channel overflows into Cache and Black rivers, and never reaches the lower end. The floodway must be planned, however, to be of sufficient capacity when the river channel in Missouri has been leveed and protected from overflow. When it is so improved, a large part of the maximum flood flow through that State must be carried outside the channel, between levees set at a considerable distance apart.

At the beginning of a heavy storm the water between these levees would be comparatively shallow, and would move slowly. As the flood flow increased, the velocity of flow also would increase, so that the flow of greater depth would tend to overtake the flow of less depth. Therefore, the increase in the rate of flood flow into the reservoir from the lower end of the 130 miles of channel would be more rapid than the increase of flow from the mountains into the upper end of this same channel. Assuming that the flow outside the channel and between levees would be 10 feet deep in time of extreme flow, with a surface slope of 1 foot to the mile, an estimate was made of the effect of the 130 miles of channel upon the flow into the reservoir, in case of the maximum storm considered in this report. The following table indicates the movement of the flood out of the hills and into the upper end of the 130 miles of channel, and the movement of the same flood out of the lower end of the channel and into the floodway of the proposed district near the state line. The principal feature to be noted is that as the flood flow increases the deeper flow of the maximum flood has a greater velocity, and tends to overtake the lower flow of the beginning of the flood, with the result that the rate

of flow increases more rapidly at the lower end of the 130 miles of channel than at the upper end.

Estimated rate of flow into and out of 130 miles of leveed channel between the Ozark Mountains and the upper end of the proposed district in time of assumed maximum storm of ten days' duration.

Day.	Flow in cubic feet per second.		Day.	Flow in cubic feet per second.	
	At outlet from hills.	At entrance to reservoir.		At outlet from hills.	At entrance to reservoir.
1	20,200		9	20,200	30,400
2	20,200		10	20,200	30,400
3	30,400		11		20,200
4	40,500	20,200	12		20,200
5	60,700	40,000	13		20,200
6	60,700	60,700			
7	40,500	60,700	Total	344,000	344,000
8	30,400	41,000			

The inflow into the upper end of the channel represents an assumed maximum storm, the exact like of which would never occur, so the table is valuable as representing a tendency rather than a particular case.

In estimating the working of the floodway and reservoir system the assumed maximum storm as noted above was considered in the modified form in which it would reach the reservoir after passing through the leveed channel between the hills and the floodway. That is, the flow into the floodway is assumed to be that represented in the second column of the above table. It is also assumed that a flow of one-fourth of an inch from the entire watershed outside the Ozarks will occur at the same time as the flood from the mountains; and no storage capacity is calculated for the reservoir, except that which is left after the water has risen to such a height that one-fourth of an inch in twenty-four hours from the entire area of flat and mountain land is flowing out of the reservoir and into the lower floodway.

Including the discharge from flat land, the inflow into the upper end of the reservoir during the flood season assumed above would be as follows: First day, 39,000 second-feet; second day, 58,800 second-feet; third day, 79,500 second-feet; fourth day, 79,500 second-feet; fifth day, 59,800 second-feet; sixth day, 49,200 second-feet; seventh day, 49,200 second feet; eighth day, 39,000 second-feet; ninth day, 39,000 second-feet.

The constant high-water flow before and after the storm is assumed to be 28,800 second-feet. If an outlet floodway 2,700 feet wide is constructed the depth of flow in it before and after the flood will be about 7 feet, and the reservoir will be filled to an elevation of 226 feet. As 231 feet has been fixed for the limit to which the water in the reservoir should be allowed to rise, there is a storage depth of 5

feet in the reservoir available for modifying the flow of extreme storms. The resulting storage capacity is about 4,700,000,000 cubic feet.

As the rate of inflow of flood water into the reservoir during a storm increases the water surface in the reservoir will rise, with the result that there will be a deeper flow into the outlet floodway. After the flood has passed the water surface of the reservoir will fall, and so there will be a lower flow into the outlet floodway. In determining the value of the reservoir for storage purposes, the variable character of both the inflow and outflow must be considered. Figure 9 represents graphically the moderating effect of the reservoir upon floods

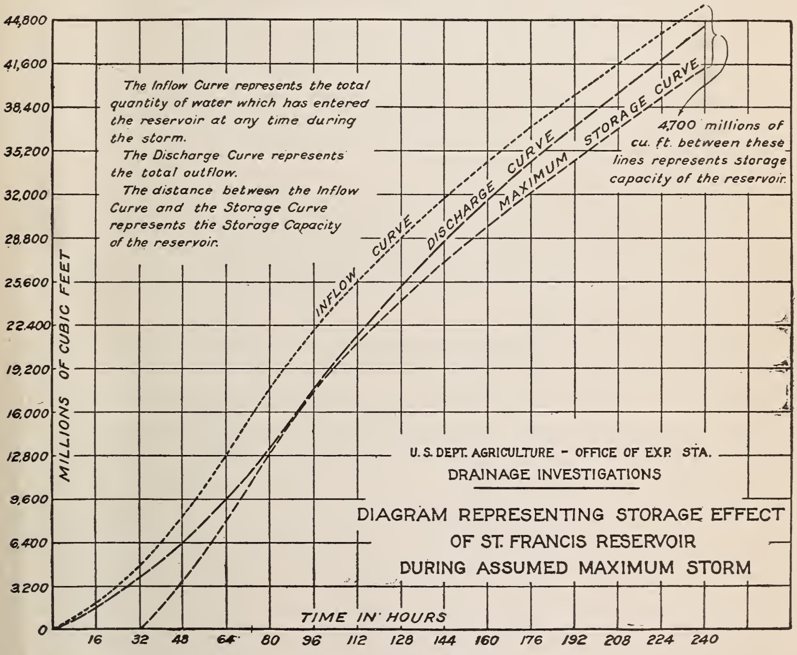


FIG. 9.—Diagram representing storage effect of St. Francis reservoir.

due to the storm considered above, and with an outlet floodway 2,700 feet wide; this width having been found to be necessary under the conditions assumed. In this figure the numbers at the left hand represent millions of cubic feet, and those at the bottom hours of time during the course of the flood. Three lines are shown in the figure. The first represents the total inflow into the reservoir during the storm. For instance, at the end of one hundred and twelve hours the amount which has flowed into the reservoir is 25,600,000,000 cubic feet. This line is marked "inflow curve." Now, since the capacity of the reservoir, as stated above, is 4,700,000,000 cubic feet

up to an elevation of 231 feet, it is evident that the excess of water which has flowed into the reservoir over that which has flowed out must never be more than 4,700,000,000 cubic feet, or the water would rise higher in the reservoir than is desired. The line on the diagram marked "maximum storage curve" is at a vertical distance from the maximum inflow curve, representing 4,700,000,000 cubic feet. As the difference between the total inflow and total outflow must never be greater than 4,700,000,000 cubic feet, if the water surface in the reservoir is to be kept below the desired elevation of 231 feet, it follows that the "discharge curve" must always fall between these two lines, if the reservoir is not to be overtaxed. After repeated trials it was found that these conditions are fulfilled where the outlet floodway is 2,700 feet wide, and the maximum discharge curve on the figure represents the outflow with a floodway of that width. The discharge curve was developed by calculating the discharge for short intervals of time and for correspondingly small increments of depth in the reservoir.

The surface of the ground along the line of the outlet floodway has not a uniform slope, and it will therefore be necessary to plan a floodway of varying width after a careful survey of the location has been made, making it wider on ground having a flat slope and narrower when the slope is greater.

The outlet floodway is planned to be 2,700 feet wide, with a maximum depth of flow of 12 feet and a maximum discharge of 75,000 second-feet. In case of a storm so extreme as that discussed the reservoir would have but small regulating effect upon the lower river. However, such a storm will probably occur not oftener than once in a generation, if at all. The increase in the proposed width of the floodway over that stated in the preliminary report was made because on a more thorough investigation of run-off conditions, it was considered possible that while the maximum flood flow considered in the preliminary report probably will never be reached, a flood may last for a longer time, and therefore more nearly exhaust the capacity of the reservoir. In all but the most extreme and unusual storms the high water flow would be of so much shorter duration, and would be so modified by the reservoir that the greatest outflow from the reservoir would be not more than half the greatest inflow into it. A more extensive examination of run-off conditions may justify a reduction of the estimated discharge, which would lead to a narrowing of the floodway to perhaps two-thirds of the width here planned and to planning lower levees. The levees are planned to extend 5 feet above the extreme high-water line as estimated above; and this again is a factor of safety which may be reduced upon further examination.

In concluding this discussion it may be said that a very large factor of safety has been used, because the run-off conditions are not well worked out. It is expected that a more thorough examination will result in very materially reducing the estimated cost of this part of the project.

THE LITTLE RIVER FLOODWAY.

In making the preliminary report a reservoir was planned at the upper end of the Little River floodway, in the bed of Big Lake. Further investigation has led to the conclusion that it is desirable to drain almost the entire bed of Big Lake, making a floodway wide enough to accommodate the entire flow. This change increases the cost to some extent, but adds perhaps 7,000 acres to the amount of land which may be redeemed, and does not increase the necessary height of the levees. The floodway is planned to be 4,000 feet wide through the lake bed, decreasing to 1,000 feet in the narrowest parts. An estimated run-off of one-fourth inch in twenty-four hours from the entire tributary drainage area of about 2,100 square miles was used in estimating the dimensions of the Little River floodway, giving an estimated total run-off of about 14,000 cubic feet per second. The first 4 miles may require to be replanned with a large dredged channel through the ridge west of Big Lake.

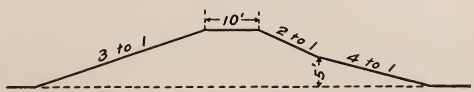
DIMENSIONS OF THE LEVEES AND DITCHES ALONG THE FLOODWAYS.

Figure 11 indicates sections adopted for the floodways. A slope of 3 to 1 has been planned on the water side of the levees, except where water will stand permanently, as in the upper part of the Little River floodway, for which a slope of 4 to 1 was adopted. On the land side of the levees a 4 to 1 slope is specified from the ground up to a line seldom reached by water, above which the slope will be 2 to 1. A crown of 10 feet is used throughout. The berm between the levee and the ditch is planned to be 50 feet wide, and a side slope of 3 to 1 is specified on the side of the ditch adjoining the levee. The ditch outside the floodway is planned to be 10 feet deep or less, with a few exceptions, while the muck ditch under the levee is planned to be 10 feet deep. It is believed that this construction as a whole is conservative and safe. Figures 10–13 give the dimensions of levees and floodways, with the amount of land occupied in the lake beds. Sections of levees are also given with the tables.

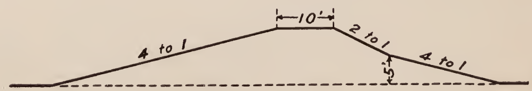
THE DITCH SYSTEM.

Figure 14, sheets 1 and 2, contains a list of all the ditches planned as a part of the completed project, including improved sections of Tyronza and St. Francis rivers, and the Right-Hand Chute of Little

STATION West Side of Reservoir	AREA OF SURVEYED LAND INSIDE OF LEVEES ACRES	AREA OF UNSURVEYED LAND INSIDE OF LEVEES ACRES	TOTAL AREA INSIDE OF LEVEES ACRES	WIDTH OF RESERVOIR IN FT.	AVERAGE BOTTOM ELEV. OF RESERVOIR IN FT.	WATER SURFACE ELEV. AT MAXIMUM FLOW	ELEVATION OF TOP OF LEVEE	WEST LEVEE					EAST LEVEE				
								LENGTH OF LEVEE IN FT.	GROUND ELEV. ALONG LEVEE LINE	HEIGHT OF LEVEE IN FT.	CROSS-SECTION OF LEVEE IN SQ. FT.	YARDAGE IN PRECEDING SECTION	LENGTH OF LEVEE IN FT.	GROUND ELEV. ALONG LEVEE LINE	HEIGHT OF LEVEE IN FT.	CROSS-SECTION OF LEVEE IN SQ. FT.	YARDAGE IN PRECEDING SECTION
2¼ mi. N. of N. Line of Craighead Co.					239.0		252.5							239.0	13.5	615.0	
N. Line Sec. 2 T.15 N., R.6 E.	0.0	0.0	0.0	11,000	239.0	245.7	251.0		239.0	12.0	505.0		11,880	239.0	12.0	505.0	246,400
N. Line Sec. 22 T.15 N., R.6 E.	470	3,900	4,370	10,000	238.0	243.3	248.5	16,000	240.0	8.5	290.5	235,700	17,100	238.0	10.5	405.5	288,300
S. Line Sec. 33 T.15 N., R.6 E.	425	2,610	3,035	6,000	233.0	239.8	245.0	17,000	239.0	6.0	265.0	174,900	19,000	233.0	12.0	505.0	320,400
S. Line Sec. 9 T.14 N., R.6 E.	35	1,480	1,515	7,000	231.0	237.8	243.0	10,800	238.0	5.0	265.0	106,000	10,600	238.0	5.0	265.0	151,200
S. Line Sec. 22 T.14 N., R.6 E.	425	1,555	1,980	5,000	228.0	235.0	240.0	15,800	234.0	6.0	265.0	155,000	16,000	232.0	8.0	265.0	157,000
S. Line Sec. 35 T.14 N., R.6 E.	300	2,410	2,710	11,000	228.0	234.0	239.0	12,300	232.0	7.0	265.0	120,700	14,400	230.0	9.0	317.5	155,300
S. Line Sec. 11 T.13 N., R.6 E.	520	2,380	2,900	10,500	225.0	232.5	237.5	10,500	231.0	6.5	265.0	103,000	11,000	228.0	9.5	345.5	135,000
S. Line Sec. 22 T.13 N., R.6 E.	1435	2,520	3,955	20,500	225.0	231.5	236.5	13,900	228.0	8.5	290.5	143,000	10,500	229.0	7.5	265.0	118,600
N. Line Sec. 5 T.12 N., R.6 E.	1990	3,480	5,470	24,300	220.0	231.0	236.0	12,500	226.0	100	375.0	154,000	11,000	226.0	10.0	375.0	130,400
N. Line Sec. 17 T.12 N., R.6 E.	980	4,875	5,855	24,500	220.0	231.0	236.0	10,400	226.0	10.0	375.0	144,400	10,700	224.0	12.0	505.0	174,400
N. Line Sec. 29 T.12 N., R.6 E.	230	5,610	5,840	23,800	219.0	231.0	236.0	10,700	224.0	12.0	505.0	174,400	10,600	224.0	12.0	505.0	198,200
N. Line Sec. 5 T.11 N., R.6 E.	230	4,500	4,730	14,600	218.0	231.0	236.0	10,700	222.0	14.0	655.0	229,800	13,500	219.0	17.0	1062.0	434,700
N. Line Sec. 16 T.11 N., R.6 E.	150	2,150	2,300	0.0	218.0	231.0	236.0	13,400	220.0	16.0	953.0	422,600	13,800	217.0	19.0	1298.0	603,000
Total	7,190	37,470	44,660					154,000				2,163,500	170,080				3,112,900



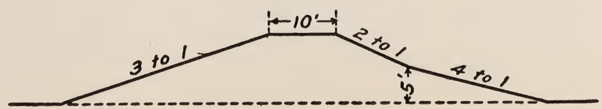
CROSS SECTION OF LEVEE FOR
UPPER FLOODWAY AND RESERVOIR
EXCEPT SOUTH END



CROSS SECTION OF LEVEE FOR
SOUTH END OF RESERVOIR

FIG. 10.—Excavation data for Upper St. Francis floodway and St. Francis reservoir.

STATION	GROUND ELEVATION	WATER SURFACE ELEV. AT MAXIMUM FLOW	WIDTH OF FLOODWAY IN FT.	DEPTH OF FLOW IN FT.	ELEVATION OF TOP OF LEVEE	HEIGHT OF LEVEE IN FT.	CROSS SECTION OF LEVEE IN FT	WEST LEVEE		EAST LEVEE	
								LENGTH OF SECTION IN FT.	YARDAGE IN PRECEDING SECTION	LENGTH OF SECTION IN FT.	YARDAGE IN PRECEDING SECTION
Frisco Railroad	219.0	231.0	2,700	12.0	236.0	17.0	917.5				
S. Line Sec. 25 & 26 T.11 N., R.5 E.	218.5	229.5	3,100	11.0	234.5	16.0	825.0	26,200	845,500	24,500	790,600
S. Line Sec. 34 T.11 N., R.5 E.	217.5	229.0	2,920	11.5	234.0	16.5	855.0	7,700	239,600	7,700	239,600
S. Line Sec. 7 & 8 T.10N., R.5 E.	216.0	227.8	2,770	11.8	233.0	17.0	917.5	18,000	590,800	18,000	590,800
S. Line Sec. 24 T.10N., R.4 E.	215.0	227.0	2,700	12.0	232.0	17.0	917.5	12,000	407,800	12,000	407,800
S. Line Poinsett County	213.0	226.3	2,300	13.3	231.5	18.5	1065.0	10,800	396,400	11,000	403,700
S. Line Sec. 34 & 35 T.9 N., R.4 E.	210.0	224.2	2,050	14.2	229.0	19.0	1117.5	35,200	1,422,600	35,200	1,422,600
½ mi. S. of S. Line of Sec. 16. T. 8 N., R.4 E.	209.0		2,000		221.0	12.0	505.0	21,400	642,000	21,400	642,000
							Total	131,300	4,544,700	129,800	4,497,100



CROSS SECTION OF LEVEE

FIG. 11.—Excavation data for St. Francis floodway.

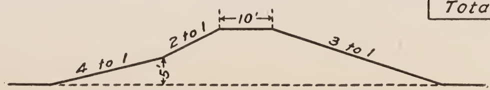
STATION West Side of Reservoir	AREA OF SURVEYED LAND INSIDE OF LEVEES ACRES	AREA OF UNSURVEYED LAND INSIDE OF LEVEES ACRES	TOTAL AREA INSIDE OF LEVEES ACRES	WIDTH OF FLOODWAY IN FT.	AVERAGE BOTTOM ELEV. OF FLOODWAY	WATER SURFACE ELEV. AT MAXIMUM FLOW	ELEVATION OF TOP OF LEVEE	WEST LEVEE					EAST LEVEE				
								LENGTH OF LEVEE IN FT.	GROUND ELEV. ALONG LEVEE LINE	HEIGHT OF LEVEE IN FT.	CROSS-SECTION OF LEVEE IN SQ. FT.	YARDAGE IN PRECEDING SECTION	LENGTH OF LEVEE IN FT.	GROUND ELEV. ALONG LEVEE LINE	HEIGHT OF LEVEE IN FT.	CROSS-SECTION OF LEVEE IN SQ. FT.	YARDAGE IN PRECEDING SECTION
Missouri-Arkansas State Line				4,000	242.5	247.7	253.0		244.0	9.0	317.5			243.0	10.0	425.0	
S. Line Sec. 33 T.16 N., R.9 E.	100	1,185	1,285	4,000	240.0	247.4	252.5	14,000	244.0	8.5	290.0	157,500	14,000	240.5	12.0	577.0	259,800
S. Line Sec. 9 T.15 N., R.9 E.	00	1,000	1,000	4,000	237.0	247.1	252.0	11,500	243.0	9.0	317.5	129,400	10,500	238.5	13.5	706.7	249,600
Centre Sec. 17 T.15 N., R.9 E.= Sta 0. of Lower Floodway	40	315	355	3,300	242.0	247.0	252.0	2,200	242.0	10.0	375.0	28,200	7,200	242.0	10.0	425.0	150,900
Total	140	2,500	2,640					27,700				315,100	31,700				660,300

CROSS SECTION OF LEVEE ON WEST SIDE

CROSS SECTION OF LEVEE ON EAST SIDE

Fig. 12.—Excavation data for upper Little River floodway through Big Lake.

STATION NO. IN MILES	WIDTH OF FLOODWAY IN FT.	GROUND ELEVATION	WATER SURFACE ELEV. AT MAXIMUM FLOW	DEPTH OF FLOW	CROSS SECTION OF FLOODWAY IN SQ. FT. BELOW WATER SURFACE	ELEVATION OF TOP OF LEVEE	HEIGHT OF LEVEE IN FT.	CROSS SECTION OF LEVEE IN SQ. FT.	YARDAGE IN ONE LEVEE	TOTAL YARDAGE IN BOTH LEVEES
0	3,300	242.0	247.0	5.0	16,500	252.0	10.0	375.0		
1	3,300	242.0	246.5	4.5	14,850	251.5	9.5	345.5	70,400	140,800
2	3,300	242.0	246.0	4.0	13,200	251.0	9.0	317.5	64,800	129,600
3	3,300	242.0	245.5	3.5	11,550	250.5	8.5	290.0	59,400	118,800
4	2,840	241.0	245.0	4.0	11,400	250.0	9.0	317.5	59,400	118,800
5	2,380	238.5	244.5	6.0	14,480	249.5	11.0	437.0	73,800	147,600
6	1,920	236.5	244.0	7.5	14,200	249.0	12.5	540.5	95,600	191,200
7	1,460	236.0	243.5	7.5	10,950	248.5	12.5	540.5	105,700	211,400
8	1,000	235.0	243.0	8.0	8,000	248.0	13.0	577.5	109,300	218,600
9	1,000	234.0	242.5	8.5	8,500	247.5	13.5	615.0	116,600	233,200
10	1,000	233.5	242.0	8.5	8,500	247.0	13.5	615.0	120,300	240,600
11	1,000	233.0	241.5	8.5	8,500	246.5	13.5	615.0	120,300	240,600
12	1,000	231.0	241.0	10.0	10,000	246.0	15.0	737.5	132,200	264,400
13	1,000	229.5	240.5	11.0	11,000	245.5	16.0	825.0	152,700	305,400
14	1,000	231.0	240.0	9.0	9,000	245.0	14.0	655.0	144,600	289,200
15	1,500	233.0	239.5	6.5	9,750	244.5	11.5	470.5	110,000	220,000
16	1,500	231.0	239.0	8.0	12,000	244.0	13.0	577.5	102,400	204,800
17	1,500	233.0	238.5	5.5	8,250	243.5	10.5	405.5	96,000	192,000
18	1,500	231.0	238.0	7.0	10,500	243.0	12.0	505.0	89,000	178,000
19	1,500	231.0	237.5	6.5	9,750	242.5	11.5	470.5	95,400	190,800
20	1,500	231.0	237.0	6.0	9,000	242.0	11.0	437.0	88,800	177,600
20¾	1,500	229.0	236.6	7.6	11,400	241.5	12.5	540.5	71,700	143,400
								Total	2,078,400	4,156,800



CROSS SECTION OF LEVEE

FIG. 13.—Excavation data for Little River floodway below Big Lake.

River, while figure 2 (p. 42) illustrates representative sections of lateral ditches. The following notes explain points not fully brought out in the tables:

The term "minimum ditch," is used to designate the smallest size planned on the project. With a fall of 1 foot to the mile, and with the water in the ditch flowing 1 foot below the ground surface, this size of ditch has a capacity of about 180 second-feet, and, according to the formula adopted for determining run-off on the lands of the interior of the district, will drain an area of between 11 and 12 square miles. In those places along the floodway where the dimensions of the ditches are determined by the requirements of the levees, the bottom widths of the ditches will vary as variations in the ground surface demand higher or lower levees. The ditches are planned to have sufficient capacity with the water surface at flood flow 1 foot below the surface.

Ditch No. 1 extends along the northern boundary of the district, from the base of Crowleys Ridge east to the floodway. The waste bank thrown to the south will form a low levee, preventing water from entering the district from the north. The ditch will collect water reaching the boundary of the district from the north and convey it to the floodway, thus preventing damage to lands outside the district by the construction of the levee. Ditch No. 1 will be a minimum ditch, except for the last mile, which will be made larger on account of the necessity for a higher levee. The levee formed by the waste bank will connect with the floodway levee, forming an unbroken line.

Ditches Nos. 2 to 9, inclusive, are minimum ditches located on parallel east and west section lines. On a part of the area drained by ditches Nos. 2 to 9 a larger run-off is estimated on account of the close nature of the soil in the region east of Crowleys Ridge. It is reported that a ditch is being constructed north and south through this territory in the bed of Big Bay. The dimensions of this ditch as reported are entirely insufficient for carrying the water of the tributary area. To use it for an outlet ditch would require it to be redredged, and this work is unnecessary, as the outlet ditch must be constructed in building the floodway levees. The most economical attitude toward the upper Big Bay ditch, therefore, is to ignore it in planning a general system.

Ditch No. 10 is a collecting ditch, located for the purpose of diverting as much water as possible into the floodway so as to save the expense of carrying it in ditches below the ground for the entire length of the district. Where it crosses the Little Bay ditch, a levee should be constructed across the latter to prevent any water from flowing south.

Ditch No. 11 for the first 10 miles will serve to collect the water of Crowleys Ridge. By giving it a proper location along the base of the

	5.5-6.0	9	12	20	7	[illegible]	1.0	784	131,400	131,400			226.0	65	Solid waste banks last ½ mile
cs	0.0-2.8	3	20.0		8		0.1	160	157,500		157,500				Side Slope 3:1 next levee
	2.8-5.0	4	21.5		8		0.3	195	129,400		129,400				" " 1:1 on land side
	5.0-5.4	5	29.0		8		0.6	540	28,200		28,200				

	7.5 - 10.0	10	12	20	7		0.5	130	54,800						

ridge a greater slope will be secured and the water carried more cheaply than if it should be allowed to flow over the surface of the ground to the lowest part of the basin, to be carried south where the slope of the ground surface is much less. This same advantage may be secured in case of the other collecting ditches. All collecting ditches along the base of Crowleys Ridge will require detailed surveys for their correct location. The run-off from their drainage areas is calculated as being three times as great as for similar areas in the interior of the district.

As a matter of fact, the run-off from Crowleys Ridge will have all the elements of hill run-off, and may exceed even the rate estimated. However, by throwing the waste banks on the downhill side of the ditches to make low banks, overflows will be effectively prevented. From its junction with No. 10 ditch No. 11 will flow east to the ditch outside the floodway, and will discharge into it. A levee should be constructed across Big Bay to prevent any water flowing down that depression, or the ditch constructed in it, and a similar levee should be built on the south side of ditch No. 11 for the last half mile of its course.

Ditch No. 12 will be excavated in building the levee on the west side of the floodway. For the first 6 miles the excavation required to build the levees is greater than that required for the ditch. Below the intersection of No. 11 a large ditch is to be constructed, with a levee on each side, discharging into the floodway 4 miles north of the south line of Craighead County. The size of the ditch is so calculated that the back water from the floodway will not cause overflows above the upper end of the secondary levee. The ditch is extended into the floodway to the old channel of the St. Francis River. From the point where it enters the floodway the inside levee is discontinued, while the outside one is extended as the floodway levee. By this device all of the water from the north part of the district is diverted into the floodway without lessening in any way the thoroughness of the drainage. After the water is discharged into the floodway, the cost of carrying it to the outlet is negligible. The undoubted advantage of this method over the system now being pursued in Craighead County can not be questioned. That the redemption of this area must be accomplished in part by leveeing the St. Francis River can not be doubted. By the policy being pursued at present in Craighead County, of draining north and south parallel to the St. Francis River, it will not be possible to divert any of the local drainage water into the floodway. If this policy were carried out the extra cost to the entire district would be perhaps $300,000 more than by the plan here presented, and this loss would have no compensating benefits. The ditches planned heretofore, however, are so entirely inadequate for thorough drainage that those south of ditch No. 11 will fit into the general system fairly well as lateral drains.

Ditches Nos. 13 to 32 are minimum lateral ditches. The run-off for those on the heavy clay soil west of Big Bay is figured as twice that from the interior of the district. The survey was not completed in the territory occupied by ditches Nos. 27 to 36.

Ditch No. 33 follows Little Bay. The ditch now being constructed down Little Bay will probably be about large enough for the place that will be left it to fill in the project; about nine-tenths of the water now tributary to it will be removed by ditches Nos. 11 and 34. It would be completely inadequate for the purpose for which it is now being constructed.

Ditches Nos. 34 and 35 are collecting ditches to be located along the base of Crowleys Ridge. It is quite probable that by building levees and check gates, where these collecting ditches cross low places along the base of the ridge, small reservoirs may be formed to supply water for rice irrigation. A very small amount of rain would keep these reservoirs supplied, as the ditches would collect water from large areas and carry it to the reservoirs. Here as elsewhere the areas tributary to collecting ditches along Crowleys Ridge are calculated to have three times as great run-off as those in the interior of the district.

Ditch No. 36 is located in the bed of Big Bay. The ditch now being planned for this location by Craighead County will be about large enough after all the other ditches here planned are constructed, and when all water from the north is cut off by ditch No. 11, but would be completely inadequate for the purpose for which it is planned.

Ditch No. 37 is a minimum ditch constructed along the south line of Poinsett County, and emptying into the floodway ditch. It is intended to leave a solid waste bank on the south side of this ditch to fully insure the area to the north from overflow in case of most extreme high water below. A flood gate at the outlet, together with the secondary levee along the floodway ditch, will complete this provision against overflow.

Ditch No. 38 extends along the floodway from the outlet of ditch No. 12 to the lower end of the floodway, where it discharges into Big Bay. The side slope next the levee is made 3 to 1, to prevent sloughing of the bank as a result of seepage through the levee base. The added section resulting from this flatter side slope, as well as the greater fall, makes necessary a somewhat narrower bottom width to this ditch than is specified for No. 36, which empties into it. The lower part of No. 38 represents a departure from the policy of having no ditches over 10 feet deep, as it has a depth of 12 feet. It is believed that the lower section will be in a heavy clay soil, and therefore will not be liable to cave. From the outlet of ditch No. 24 to the south line of Poinsett County a small secondary levee, perhaps 4 feet high, should be constructed on the west side of this ditch, and solid waste banks should be left along the lower parts of ditches 25, 26, 35, and 36, where the elevation of the ground is below 218.

Small wooden flood gates through the waste banks of these ditches may be found to be necessary in case of unprecedented high water in the St. Francis River, causing an insufficient outlet for ditch No. 38. It is not believed that any such recourse will be necessary, but there is a remote possibility that it will be, for a few days at a time, at intervals of several years.

From its upper end to the outlet of ditch No. 36, No. 38 must be constructed larger than is necessary in order to build the floodway levees, but below the outlet of ditch No. 36 the excavation for the ditch is much greater than that needed to build the levees. If the work is done by a hydraulic suction dredge, nearly all the excavated material should be placed in the levee, as the additional strength of the levee would be a desirable factor in the development of a power plant at the lower end, requiring a dam across the floodway.

The outlet of this ditch will require either a narrower and deeper section, or an overfall weir, to prevent the ditch washing out and damaging the levee.

Ditch No. 39, located along the Missouri-Arkansas line, and carrying drainage water from Missouri west into the St. Francis floodway, will have a solid waste bank or levee on the south side, and will perform a function similar to that of ditch No. 1, in preventing the overflow of the district from the north. With a bottom width of 40 to 50 feet, it will alleviate overflow conditions in Missouri, but will not be large enough to drain completely the land tributary to it in Missouri. If the St. Francis River is leveed in Missouri there will be an undrained pocket in that State where this ditch and the levee unite, unless some method is adopted to complete the reclamation. This can be effected by continuing ditch No. 39 at a distance of 100 or 200 feet west of No. 58, and building a levee to the west of No. 39, the ditch being extended southward with a very flat gradient, until the back water in it from the floodway will not affect the land to be drained in Missouri.

Nos. 40 to 51 are minimum ditches. For Nos. 40 to 46 incomplete surveys were made. It may be desirable to leave solid waste banks 2 or 3 feet high along the lower courses of Nos. 44 to 49, with openings which may be closed in time of the most exceptional high water. This protection probably will never be necessary.

No. 52 for the first 7 miles is a minimum ditch, having a bottom width of 16 feet and a depth of 7 feet.

Ditches No. 53 to 56 are of minimum size.

Ditch No. 57 is an outlet for numerous other laterals.

Solid waste banks, with openings which may be closed in time of most extreme high water in the floodway, may possibly be necessary near the outlets of ditches Nos. 54 to 57 for protection in time of most extreme floods.

Ditch No. 58 extends along the east side of the St. Francis floodway, to receive all water from ditches 40 to 57. It may be found desirable to locate this ditch in the depression east of Cane Island, building the levee as high as is necessary on the west side of the island. The side slope of this ditch next the levee will be 3 to 1, and on the opposite side 1 to 1. A small secondary levee 2 to 4 feet high may be necessary on the east side of the ditch, from ditch No. 44 to the outlet, with openings which can be closed in time of most extreme high water in the floodway. For the last $3\frac{1}{2}$ miles the secondary levee should be about equal to the outside levee in height. It will be built partly by the excavation from ditch No. 103. Ditch No. 58 discharges into the St. Francis floodway at the outlet of the Little River floodway.

Ditch No. 59 is entirely similar to No. 39, except that it flows east into the Little River floodway, and all remarks concerning the former ditch apply equally to it.

Nos. 60 to 68 are minimum ditches, emptying into ditch No. 69.

No. 69 extends along the west side of the Little River floodway, being formed of the excavation for building levees; and for this reason throughout most of its course it is larger than is necessary for carrying the tributary drainage water. From the outlet of ditch No. 68 a secondary levee will restrain the water in this ditch to prevent it from overflowing in time of high water in the St. Francis floodway. The part of this secondary levee in Mississippi County is built by the excavation from ditch No. 104. The side slope of ditch 69 next the levee will be 3 to 1, and on the other side 1 to 1. The ditch empties into the St. Francis floodway, and extends half a mile into the floodway to the old channel of the St. Francis River, in order to furnish a low-water outlet.

Ditches Nos. 70 to 75 are designed to drain the northeast corner of Mississippi County into the Little River floodway, including the run-off from a small area in the extreme southeast corner of Missouri, which will not be diverted to the west by Missouri ditches now under construction. A very considerable saving will be effected by this plan over the cost of carrying this drainage water below the ground surface to the south side of Poinsett County. The drainage can be made as complete in one case as in the other.

Nos. 70 and 72 will require no excavation, being located in existing channels.

No. 71 drains Walkers Lake into Pemiscot Bayou.

No. 73 drains Flat Lake into Pemiscot Bayou.

No. 74 follows the old outlet of Flat Lake, into Pemiscot Bayou, and thence follows that bayou north for about 4 miles. It will require very little excavation.

Ditch No. 75 begins in Buford Lake, extending through Grassy Lake to Pemiscot Bayou and down that bayou to the point where the

bayou turns south. From here the ditch extends about a mile to the northwest, to a point a few hundred feet from the state line, and thence west parallel to and a few hundred feet south of the state line to the Little River floodway. A levee will be constructed for the last 8 miles by the earth excavated, to protect the bed of Big Lake from overflow from Missouri. The region in Missouri just north of this levee, which is too low for gravity drainage into the Little River floodway, will require to be leveed on all sides, and either to be pumped out or to be drained by an inverted siphon under the levee and ditch No. 75. This latter method is entirely practicable, and ditch No. 96 is made of sufficient capacity to carry the water. The expense of the reclamation would, of course, fall upon Missouri lands.

Nos. 76 to 85 are minimum ditches and empty into ditch No. 126 on the east side of the lower Little River floodway.

Nos. 86 to 95 are minimum ditches emptying into ditch No. 96. No. 91 may require a solid waste bank for the last half mile, with openings which may be closed in time of most extreme high water. No. 93 should have a levee on the east side for the last mile, with a small flood gate at its outlet, allowing drainage water from the very low land just to the north to enter the ditch. It is probable that the flood gate here never will be needed, and certainly will not be needed oftener than once in several years.

Ditch No. 96 at its upper end is formed by the construction of the Little River floodway levee. From the point where the floodway leaves Big Lake this ditch will run south to the Right-Hand Chute of Little River, and will follow the course of that stream to the west quarter corner of section 11, township 13 north, range 8 east. From this point the channel of Right-Hand Chute is abandoned, while the ditch bears due west, emptying into ditch No. 126 outside the Little River floodway. The use of Right-Hand Chute for a drainage channel is one of the more unsatisfactory features of this project. In order to drain the bed of Big Lake the depth of this channel must be increased to from 14 to 18 feet, and it is not certain how well the banks will stand at this depth, especially in a crooked channel. However, it seemed to be the only economical method to employ, and if the channel fills with sand or forms bars it will require to be redredged. No other economical use can be made of this channel. It is wholly impossible as a location for the floodway, as the bottom of the stream is higher than the land on which the floodway is located, while the extreme high water in the floodway will be 2 to 4 feet below the surface of the ground along the banks of this channel.

At the point where Right-Hand Chute is abandoned it has become so small and crooked as to be of little use for a main drainage channel. Moreover, by constructing the ditch along the floodway, the same excavation which forms the ditch will furnish material for building

the levees. The remainder of Right-Hand Chute performs the function of a lateral drain, and is not of sufficient capacity in an unimproved condition to drain even the small remaining watershed tributary to it. In the lower part of the bed of Big Lake, ditch No. 96 may require continuous waste banks, with flood gates for drainage in time of high water. As in other similar situations on this project, the drainage will be perfect without such continuous waste banks, except in time of very high water, such as might occur at intervals of several years.

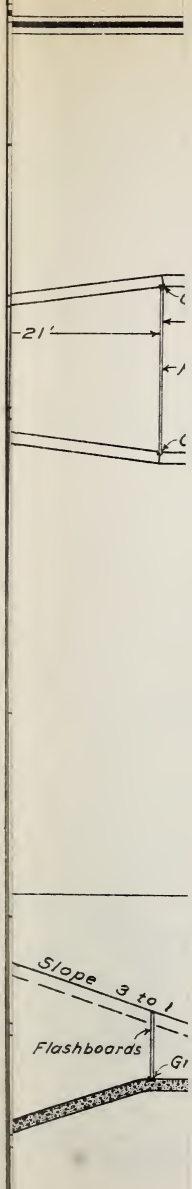
No. 97 is a minimum ditch running east and west and emptying into the ditch east of the Little River floodway near the line between Mississippi and Craighead counties.

Nos. 98 to 103 are minimum ditches draining a pocket behind the junction of the St. Francis and the Little River floodways. The excavation from No. 103 will be used in making a secondary levee east of No. 58.

No. 104 is parallel to the Little River floodway and lies north of ditch No. 65, there being a secondary levee between them. It receives the water from ditches Nos. 98 to 103 and discharges through an inverted siphon underneath the Little River floodway and empties into ditch No. 126 outside of the St. Francis floodway. The drainage of this pocket can be secured by no other method, unless pumping is resorted to, which in the long run would be far more expensive than the construction of the inverted siphon. For the ditch system the same run-off is calculated as for the other ditches in the interior of the district, but, in designing the inverted siphon, a run-off of 1 inch in twenty-four hours from the entire watershed of the pocket is assumed, for the re[illegible] at this construction can not be enlarged economically after it is [illegible] constructed, and it is desirable to have it of such size that there is no danger of its not having sufficient capacity. The construction of the siphon is illustrated in figure 15 and a section of the Little River floodway at the location of the siphon is illustrated in figure 16. As wide a berm as possible should be left between No. 104 and No. 69. The channel of No. 104 above the culvert should be constructed very much larger for a few hundred feet to furnish a basin for catching sand and silt, which otherwise would enter the culvert. This pocket can be cleaned out occasionally, if necessary.

Nos. 105 to 111 are minimum ditches emptying into No. 126 outside the St. Francis reservoir.

Nos. 112 to 116 are minimum ditches emptying into the Right-Hand Chute below the outlet of No. 96. The natural channel has sufficient capacity to dispose of the discharge from these ditches without any improvement as far south as ditch No. 117.



T END

No. 117 diverts the water of the Right-Hand Chute to the west into ditch No. 126, as the channel of the Right-Hand Chute is too small below this point to carry the water.

Nos. 118 to 121 are minimum ditches in Poinsett County below the St. Louis and San Francisco Railroad, emptying into No. 126.

Nos. 122 to 124 are minimum ditches discharging into No. 125.

No. 125 is a minimum ditch for the first 7 miles and for the remainder of the distance is 8 feet deep with a 12-foot bottom, and with 1 to 1 side slopes. A small levee will be constructed to the south and east of No. 125 by depositing the waste bank of the ditch to the south and east, and at its outlet into No. 126 a flood gate will be constructed, which, with the secondary levee along the east side of No. 126, will effectively protect the inclosed area from overflow in case high water in the lower St. Francis results in an insufficient outlet for the ditch along the floodway. It is improbable that this protection ever will be needed, but its adoption is recommended as a factor of safety.

No. 126 is located on the east side of the Little River floodway, the St. Francis reservoir and the St. Francis floodway. It begins about 2½ miles from the point where the Little River floodway leaves Big Lake. The levee on the east side of the floodway between this point and Big Lake will be made by a ditch constructed inside the floodway. For the first 12 miles, to the outlet of No. 96, the size of the ditch is determined by the excavation necessary for building the levee. From this point to the St. Francis reservoir an average depth of 13 feet is necessary in order to secure a sufficient outlet for the inverted siphon under the Little River floodway. From the outlet of No. 117 to the St. Louis and San Francisco Railroad a greater excavation is necessary for the ditch than is required to build a levee, the result being that the levee along this section will have greater dimensions than is indicated in the specifications. At the point where ditch No. 126 crosses the lower channel of the St. Francis River 1,000 cubic feet per second of the extreme flood flow will be diverted into the river channel, and the remainder, or about 1,300 second-feet, will be carried

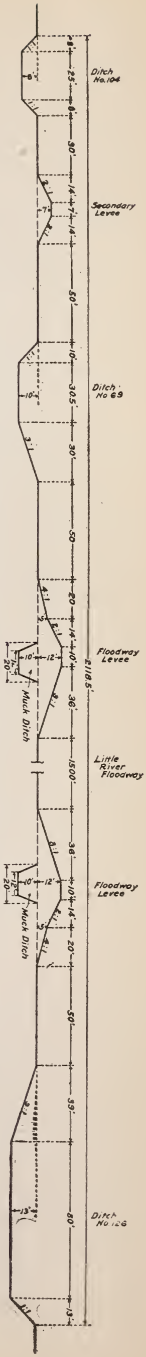


Fig. 16.—Typical cross section of Little River floodway at lower end.

in the remaining portion of the ditch. A secondary levee may possibly be required for about 4 miles above the St. Louis and San Francisco Railroad, in order to prevent the overflow of the ditch onto the lowlands now occupied by St. Francis Lake, and a similar levee will be required from the outlet of ditch No. 121 to the outlet of ditch No. 125. From the St. Louis and San Francisco Railroad to a point 6 miles south of the south line of Poinsett County the excavation required for digging the ditch is the same as that needed for the levee. From the latter point to the end of the floodway a greater excavation is required for digging the ditch than for building the levee. The lower end of No. 126 will require to be deepened or protected by a weir to prevent its cutting to a greater width than is desired during high water flow, and thus endangering the lower section of the levee.

Nos. 127 and 128 are minimum ditches lying between the Right-Hand and Left-Hand chutes of the Little River and emptying into the Left-Hand Chute.

Nos. 129 and 130 are minimum ditches draining shallow lakes east of Little River into that stream.

No. 131 is a minimum ditch draining into Little River, a small cypress lake just east of Le Panto.

Nos. 132 to 134 are minimum ditches lying between the Right-Hand and Left-Hand chutes of Little River, and draining into the latter stream.

No. 135 is a minimum ditch draining a part of the bed of the St. Francis Lake into the Right-Hand Chute of the Little River near its outlet into the St. Francis River.

No. 136 is an improvement of the St. Francis River between the reservoir and the outlet of the Right-Hand Chute. Only enough excavation will be required to construct a levee 4 feet high on each side of this stream. Probably such a levee never will be necessary, but it is designed to secure fully the low-lying lands of the St. Francis Lake bed from overflow.

Nos. 137 and 138 are minimum ditches on the east side of the St. Francis River near the south line of Poinsett County, emptying into the St. Francis River.

Nos. 139 and 140 lie west of the St. Francis River about 4 miles above the south line of Poinsett County, and empty into Steep Gut Slough.

No. 141 is a minimum ditch east of the St. Francis River on the south line of Poinsett County, emptying into Broad Mouth Lake, whence the water will reach the St. Francis River.

No. 142 is a minimum ditch west of the St. Francis River near the south line of Poinsett County, emptying into Fortune Slough.

No. 143 is an enlargement of the Tyronza cut-off in Mississippi County, designed to carry half the water of No. 156. It is designed with a 30-foot bottom and a 4-foot cut, and empties into No. 177.

Nos. 144 to 146 are minimum ditches emptying into an existing ditch 3 or 4 miles north of Luxora.

Nos. 147 and 148 are minimum ditches northwest of Luxora emptying into No. 156.

Nos. 149 and 150 are minimum ditches emptying into No. 151.

No. 151 has a 20-foot bottom and a depth of 8 feet and empties into No. 156.

Nos. 152 and 153 are minimum ditches emptying into No. 156.

No. 154 is a minimum ditch discharging into No. 155.

No. 155 is 23.5 miles long, lying east of the Little River and in general parallel to it, and empties into No. 156.

No. 156 is 25.2 miles long. One-half of this water is discharged through the Tyronza cut-off into the Tyronza River, while the remainder empties into the same stream farther south. All of the low water flow passes to the outlet of No. 156.

Nos. 157 to 164 are minimum ditches east of the Tyronza Lake area, emptying into ditch No. 165.

No. 165 is parallel to the old ditch which was intended to drain this territory, and is 25.2 miles long. It will receive about 1,200 cubic feet per second. From the outlet of ditch No. 8 of Mississippi County an extra depth of 4 feet, making a total cut of 16 feet, is required to make the depth of ditch No. 165 equal to that of the outlet ditch for district No. 8. No. 165 empties into ditch No. 177.

Nos. 166 to 176 are minimum ditches emptying into No. 177. More data is required for the proper location of Nos. 170 to 172.

No. 177 for the first 3.2 miles is a new ditch located about 1 mile north of Luxora. The next 17.5 miles is an improvement of an existing ditch and the remainder is an improvement of the Tyronza River. As it is necessary to give the Tyronza River a greater depth than that at which the banks can be depended upon to maintain themselves in the earth of this region, a channel is planned of such size as to have ample capacity, after a certain amount of deterioration has taken place through bars forming in the channel, so that even if the maintenance is imperfect no repairs will be required for a considerable number of years. A ditch which is now being constructed from Dead Timber Lake to Big Creek, near the north part of Crittenden County, is intended to divert a considerable part of the water of the Tyronza River into Big Creek. If the region about Tyronza Lake is to be redeemed it will necessitate a water level in the Tyronza River so low in the ground that this cut-off between Dead Timber Lake and Big Creek will be entirely useless for carrying water from Tyronza River; in fact, in any improved channel of the Tyronza River, as planned, the extreme high-water line will be lower than the bottom of the cut-off ditch between Dead Timber Lake and Big Creek, so that instead of flowing through this cut-off the water of Dead Timber

Lake would flow north into the Tyronza River. This is an illustration of the great loss which is bound to result from efforts to redeem this region by small districts having no relation to each other.

Nos. 178 to 180 are minimum ditches emptying into No. 181.

Nos. 181 to 185 empty into Dead Timber Lake. More data are needed to determine their proper location.

CROSSINGS AND BRIDGES.

The Little River floodway will cross the right of way of the Jonesboro, Lake City and Eastern and of the Paragould and Memphis Railroad. In each case a pile bridge will be required across the floodway. The Jonesboro, Lake City and Eastern Railway also crosses the St. Francis Lake at Lake City and will require new approaches upon the construction of the floodway system. The St. Francis floodway will cross the St. Louis and San Francisco Railway through two existing pile trestles, and the only interference here will be in arranging for the passage of excavating machinery under the bridges. These are the only instances of the crossing of railroads by the floodway system. The system of lateral ditches is planned so as to require a minimum number of railroad crossings, and none of these is through a high grade. But few wagon roads will be interfered with. Two public highways are crossed by the right of way of the St. Francis floodway, and perhaps one by the Little River floodway. The cost of constructing crossings for highways and railroads over the floodways is estimated as a part of the cost of the project. Other crossings and bridges should not be charged against the drainage project.

MINOR LEVEES, FLOOD GATES, AND OTHER CONSTRUCTIONS.

In a few instances tracts of land are so low that it is not practicable to plan for their drainage by gravity during extreme high water. In these cases small levees may be made by leaving continuous waste banks in digging the ditches, and flood gates will protect the areas drained from overflow by extreme high water in the ditches. This arrangement is planned for a small area at the south end of Big Lake, for another area at the south end of St. Francis Lake, for the land adjoining the St. Francis floodway just north of the south line of Poinsett County and above its junction with the Little River floodway. Such protection will not be required except in time of most extreme floods, at intervals of several years, and experience may prove that it will not be needed at all. The provisions are included in the plan to make entirely sure the efficiency of the proposed system.

Where the Little River floodway enters the St. Francis reservoir an inverted siphon will be required to carry under the floodway the water from an area too low to be drained into it. A concrete culvert is planned for this construction, as illustrated in figure 15, page 74. No other unusual constructions are required by the plans.

RESULTS TO BE EXPECTED.

COMPLETENESS OF DRAINAGE.

One of the objects of this report is to indicate the amount of work necessary to drain thoroughly and completely all parts of the proposed district in Mississippi, Craighead, and Poinsett counties, Ark. It is believed that the construction of the system as planned, with such modifications as a detailed survey would suggest, will fully accomplish this purpose for practically every acre within that area, excepting, of course, the land within the floodways and reservoirs. Large areas in Cross and Crittenden counties also will be improved.

By complete drainage is meant the removal of surface water so quickly that the land never will be flooded, and the maintenance of the water surface in the ditches at least 3 feet below the surface in ordinary high water, with tile outlets 4 or 5 feet below the surface. The removal of surface water three or four days to two weeks after it falls as rain does not constitute good drainage, and land which is drained in this manner will have but a fraction of the value of that which is thoroughly redeemed. Experience in the lowlands of Missouri has established the fact that these low, flat areas require ditches at intervals of not more than 1 mile for thorough drainage. Further investigations may indicate that in some of the sandy soils ditches may be placed farther apart, and such investigations also will probably indicate that some of the lateral ditches throughout the district may be made smaller.

The construction of the floodway system, with the improvement of Tyronza River and the Right-Hand Chute of Little River and ditches along the state line, will result in making perhaps a third or a half of the land in the district tillable, even if no lateral drains should be constructed at the time. Overflows would be entirely prevented, except for water from Crowleys Ridge, and the land on ridges would receive fairly complete drainage. The ditches outside the floodway would drain the adjoining land for a considerable distance and furnish outlets for all depressions or sloughs which are intercepted. The construction of the floodways also would give complete relief to lumbering operations throughout almost every part of the district. With this amount of work completed the remaining ditches could be constructed from time to time as demanded.

HEALTH CONDITIONS.

The agricultural development of this district is to a considerable extent dependent upon its settlement by persons coming from near-by States on the north and east, and perhaps no other change in present conditions aside from drainage would prove to be so great a stimulus

to immigration from that section as the practical elimination of malaria. This disease is perhaps no more prevalent in northeastern Arkansas to-day than it was in Illinois and Indiana a generation ago. In the parts of these latter States which have been thoroughly drained malaria has become almost a thing of the past, and with the thorough drainage of this region it will probably pass away here as well.

The fact has become thoroughly established that certain species of mosquitoes are responsible for the spread of malaria, and that no malaria exists where none of these mosquitoes are found. It is known, moreover, that these mosquitoes breed in shallow, stagnant water and seldom come to maturity in water in which there are fish or minnows. The thorough drainage of this territory will doubtless help greatly to control the disease.

FISHERIES.

In the construction and maintenance of the St. Francis reservoir the development of fisheries should not be overlooked. The importance of this subject may be inferred from the following reference to the value of fisheries in the submerged areas along the lower Illinois River, on page 54 of the Illinois Waterway Report of 1909:

> The 80,000 acres of submerged lands have a high value for fish culture, the present yield bringing $10 per acre to the fisherman while the consumer pays double. It is not too much to expect that this crop will increase to a value of $15 to $20 per acre in the future, or amount to $1,200,000 to $1,600,000 annually. Any policy of reclamation should zealously guard this source of wealth.

The St. Francis reservoir would have an area somewhat larger than that above mentioned, nearly all of which is now declared to be government property.

On taking up the subject with the Bureau of Fisheries of the Department of Commerce and Labor, the acting commissioner stated that the value of fisheries of the proposed St. Francis reservoir would perhaps be greater than that of any artificial reservoir in the United States. In a letter on this subject he states:

> This office is strongly imbued with the belief that there are here presented great possibilities for augmenting the food supply for a large area, providing business and pleasure for many people, insuring the preservation and increase of the food and game fishes, and establishing a fish nursery of which the surplus production may be used for the stocking of other waters.

He further states that the Bureau of Fisheries would cooperate with the district to the fullest possible extent in developing the fisheries value of the reservoir. Whether the area should be developed for commercial fishing, as has been done on the Illinois River, or whether the district as a whole would derive a larger income from it as a fishing and hunting reserve, thus attracting a large number of people to this region during the hunting and fishing season, is a

subject requiring careful consideration. In any event, it appears that the St. Francis reservoir may become a very important source of revenue.

RICE IRRIGATION.

The cost of irrigating rice is from $5 to $10 per acre per year. The water in the St. Francis floodway and reservoir flowing above the surface of the ground would furnish a supply of water by gravity for many thousands of acres of rice in the area west of the floodway. Water from this source could be furnished at half the cost of present methods of irrigation and at the same time return a considerable income to the district. The great area of the watershed would insure an unfailing supply of water, which would be required for the most part during a season when there would be an abundant flow, so that the use of water for this purpose would not greatly interfere with its use for power. Moreover, the water would have two to four times the value for irrigation which it would have for developing water power.

With the further development of this territory the ability to procure a gravity supply of water for irrigating such crops as potatoes, sweet potatoes, cabbages, and celery for the northern market may become an important consideration. Small reservoirs for rice irrigation may be formed in the construction of collecting ditches along the base of Crowleys Ridge.

ROAD IMPROVEMENT.

In the development of an efficient highway system, thorough drainage for the roadway foundation is indispensable. No other factor in road building is of greater importance. The improvement of the proposed district according to the plan submitted would produce excellent surface conditions for a complete system of highways. In addition, many of the lateral ditches are so laid out as to be good locations for roads, and their waste banks, on being graded down, would require little improvement except surfacing.

LUMBERING.

Lumbering operations are now much interfered with through the difficulty of hauling during the wet seasons. In fact many parts of the district are so wet that lumbering can not be carried on economically at any time of the year. The construction of the proposed floodway system, with the proposed improvement of Tyronza River and Right-Hand Chute, and the smaller ditches along the state line, would accomplish as thorough drainage for almost the entire territory as would be needed for lumbering operations. A large number of lateral ditches will be necessary to redeem the land fully for agricultural purposes, but except in a few instances, such lateral ditches

will not be necessary until the land is cleared. It is a notable fact that in the promotion of many large drainage projects in the lower Mississippi Valley lumbermen have been among those most actively promoting the improvements, on account of the benefits received directly through the reduced cost of operation.

RAILROADS.

The benefits of the proposed improvement to railroad companies would be of two kinds: First, the actual benefit to the right of way through making a more stable roadbed and in reducing the cost of maintenance; and, second, by increasing the business of the road through the development of the district. The first-mentioned benefit is probably the only one for which the railroads may legally be assessed, but the latter is by far the more important, and in view of this fact the railroads can well afford to adopt a liberal policy of encouragement to the district. The region is now nearly a waste, except for a strip of land along the Mississippi River, and furnishes little traffic to the railroads except in lumber. With thorough drainage and development it will probably be capable of supporting a denser population than any other region tributary to the roads which pass through it.

POWER.

The generation of water power in the Yazoo-Mississippi Delta never has been undertaken, and at first thought would seem to be impracticable. Yet in this drainage project the opportunity exists for the development of a power plant which would be of large value in any growing part of the country, and should be all the more important here because it would meet with little if any competition from other water-power plants in the same region.

The conditions which make a power plant possible as a part of this project are these:

(1) The St. Francis floodway must carry the water from about 4,500 square miles of drainage area.

(2) This water will flow over the surface of the ground between levees, and at the lower end will fall 17 feet to the ordinary low-water surface in Big Bay. By maintaining a low dam across the mouth of the floodway this head may be increased to 25 feet without interfering with the safe operation of the floodway.

(3) The St. Francis reservoir may be used for storing water for power purposes without interfering with the use planned for it for flood storage.

Here are the three essential elements necessary for the production of power: A large drainage area in a humid region; opportunity for equalizing the flow; and a sufficient fall to produce power. The

amount of flow at low-water stage can not be determined accurately in advance of the construction of the drainage system, but it is believed, from a comparison of this with other streams, that it will not fall below 1,000 cubic feet per second. By the storage of 4 feet of water in the St. Francis reservoir this flow can be doubled or brought to a minimum of 2,000 second-feet, and this would not affect the use of the reservoir for flood storage, as outlined in this report. Further provision for storage would make available 3,000 second-feet in time of lowest water. Considering that 60 per cent of the theoretical horsepower from 2,000 second-feet falling 25 feet could be delivered as far away as Memphis (35 miles), the result would be about 3,500 horsepower delivered at that city or at a point equally distant.

The cost of this development would be appoximately as follows:

Dam at lower end of St. Francis floodway	$100,000
Reenforcement of levees at lower end	50,000
Three storage weirs in St. Francis floodway and reservoir	30,000
Generators and transformers	75,000
Transmission line	20,000
Water wheels and accessories	25,000
Reserve equipment	50,000
Total first cost	350,000
Annual cost:	
5 per cent interest on investment	17,500
Depreciation and repair, 10 per cent	35,000
Cost of operation	20,000
5 per cent sinking fund	17,500
Total	90,000
Income when entire minimum supply is used:	
3,500 horsepower, at $75 per annum	262,500
Profit over annual cost	172,500

The reservoir at the head of the floodway would make possible the use of the water during all or a part of the day, as might be necessary, so that, instead of 3,500 horsepower for twenty-four hours, the production could be made 8,400 horsepower for ten hours. It is a common practice to sell electrical power at a given amount per horsepower per year, the charge each month to be based upon the highest amount used at any time during that month. As not all plants supplied by a system will use a maximum amount of power at the same time, it is common practice for the producing plant to sell two to four times as much power as is represented by the capacity of the plant. If all the power were sold in this way at the rate of $25 per horsepower per year to plants running ten hours a day the income would probably exceed $75 per horsepower for the entire capacity of the plant. So far as is known no power is now being sold in the

Yazoo-Mississippi Delta for less than $120 per horsepower per year for power actually used. The usual rate in small towns using electric light is about 10 cents per kilowatt hour, or about $650 per horsepower per year. It is believed that the lowest rate at which power is sold in Memphis is $130 per horsepower per year for power actually used to guaranteed users of large amounts.

Memphis, being within easy reach, would furnish the best market for power at the present time. This city now uses about four times as much power as would be available from this plant. It would probably be advisable, also, to build a transmission line through Wynne, Harrisburg, and Nettleton to Jonesboro. As the actual cost of producing electric power by the small plants in these towns is $200 to $400 per horsepower per year, the opportunity to purchase cheap power would be a great benefit. Other immediate uses would be pumping water for rice irrigation and for the operation of cotton gins. As the country develops the power can be used for operating electric railways and factories. In general, it may be said that the possession of a large supply of cheap power would put this district in the favorable position which is always held by communities having this resource.

The commercial eminence of Massachusetts has resulted from the development of water power. Yet only one river in that State has as large a drainage area as that here considered; the rainfall is nearly 50 per cent less; the flow is more irregular, owing to the passing off of most of the winter snow in a few weeks of spring flood; and such unusual opportunities for regulating flow as would result from the construction of the St. Francis reservoir do not exist. In fact, the power plant at the lower end of the St. Francis floodway would probably be superior to any plant in Massachusetts.

FINANCIAL RETURNS.

Two or three years would probably be required to bring this project to a paying basis, as a market for the power would have to be secured. In the long run the income should go far toward paying the interest on the cost of the entire floodway system. The amount of power available could be approximately doubled by strengthening the reservoir system and installing an auxiliary steam plant for use during periods of exceptional drought. Should local markets for the power develop so as to make this further increase desirable, the profits under a good management should be sufficient to pay interest and sinking fund and all cost of maintenance on the floodway system. It probably will be necessary to install an auxiliary steam plant to furnish power during brief flood periods when little head would be available on account of high water in the St. Francis River. and this

plant would increase the minimum amount of power to be furnished during extreme dry periods.

The two advantages of the development of this water power would be, first, the financial returns which would lighten the burden of the drainage development, and, second, the stimulus to industrial development in the community which would result from cheap power. The plant should remain the property of the district, and the power should be used, as far as possible, in supplying the local needs of the district for light and power.

WATERWAYS AND WATER TRANSPORTATION.

The vigorous campaign now being made for a system of internal waterways is familiar to every one. Against this movement stands the fact that despite the improvement of the rivers and canals their use continues to decline from year to year, and it still remains to be seen whether canal transportation will ever again compete, to an important degree, with transportation by rail. Yet in the opinion of many students of the subject, water transportation must be a very important factor in the full development of the country. This being the present status of the subject, it would not be wise to spend a large amount of money in making water transportation possible in the proposed district, until it is fully proved that such a course would be profitable; while, on the other hand, to destroy the possibility of internal waterway development in devising a system of drainage would be doubly unwise. An improvement of this district at the present time should not include large expenditures for waterways, but should with great care conserve to the future every possibility for this development; and this is the course which has been pursued in the preparation of these plans.

Some of the foremost engineers, in considering methods of securing a transportation channel through the Mississippi Valley, have come to the conclusion that this result may best be accomplished by leaving the Mississippi River channel and constructing a slack-water channel in the lower part of the valley away from the river. The floodway channel of this project, in connection with the floodway planned as a part of the Little River district in Missouri, would furnish a right of way for such a transportation channel from a point near Cape Girardeau to the St. Francis River near Parkin, a distance of more than 150 miles in a straight line. The reservoirs planned on these two projects would furnish a sufficient supply of water for such a channel, and the construction of a transportation canal inside the floodway levees would not in any way interfere with the drainage of the country.

In both first cost and maintenance, the construction of such a channel for 14-foot navigation would probably be far cheaper than

the improvement of the Mississippi. It might be continued down the St. Francis River to its mouth, and, there crossing the Mississippi River, be extended through the Yazoo Valley, entering the Mississippi River again at Vicksburg.

The effect of the construction proposed in this report would be to improve the condition for navigation of all of the drainage channels of the district, except the Left-Hand Chute of Little River, and the St. Francis River between Marked Tree and Parkin. The ditches outside the floodways will carry water of sufficient depth for any boats which now operate on the rivers. The Tyronza River and the Right-Hand Chute of Little River will be improved so as to carry much larger boats than they will at present. The Right-Hand Chute of Little River, with the continuing ditch down the outside of the St. Francis reservoir, will form a better transportation channel than the Left-Hand Chute ever has been. The St. Francis reservoir and ditch No. 12 would be navigable for boats of a 5-foot draft at any time of the year as far upstream as Lake City.

At a cost of $50,000 to $75,000 in addition to that required for the proposed power plant, a transportation channel with a minimum depth of water during dry seasons of 5 feet and a minimum width of 30 feet can be made throughout the entire floodway and reservoir system. This channel would be secured by constructing across the floodway dams about 5 feet high, supplied with locks, and by excavating between the dams a channel having a minimum depth of water of 5 feet during low water. These dams would raise the water level at flood flow less than 6 inches, according to Merriman's formula for the flow of water over submerged weirs.

In compliance with the river and harbor act of June 3, 1896, a survey of the lower St. Francis River was made under direction of the Chief of Engineers of the U. S. Army to determine the practicability of making the lower part of that river navigable. In that report the cost of obtaining 3-foot navigation to Wittsburg in time of low water is placed at about $1,000,000 and the recommendation is made that the project is not feasible at the present time. When it is considered that this is the largest part of the St. Francis channel and was looked upon as the only part concerning which there was any prospect of improvement to gain a navigable depth of 3 feet, it is seen that the upper St. Francis River is in effect not a navigable stream and can not be made such at any reasonable expense.

The proposed St. Francis reservoir, if combined with a power plant, would regulate the flow of that stream by making the low-water discharge about three times what it is at present, and probably would result in greater benefit than the expenditure of $1,000,000 in improving the lower river. By the moderation of floods in the reservoir the formation of sand bars would be less rapid, and the higher low-water stage would tend to hold a deeper channel.

The St. Francis River above the mouth of Big Bay, as recommended by the engineers of the War Department for the St. Francis River in Missouri,[a] should be declared by act of Congress to be not navigable, and the drainage improvement of the region should be allowed to progress without hindrance. At present even small gasoline boats can not travel on the river from Marked Tree to Parkin during several months in the year. With the construction of the proposed drainage system the ditches outside the floodways will form better drainage channels than the river does at present, while in the floodway itself is the possibility of developing a valuable transportation system.

EFFECT OF THE SYSTEM UPON MISSOURI.

The Little River floodway would be a continuation of a similar construction in Missouri. As the Hornersville Ridge lies just to the west of the Missouri floodway, there would be little if any land on that side affected by the stage of water on the Arkansas side. Just to the east of the Little River channel and north of the state line is a tract marked as area No. 2, on the map opposite page 8, which is too low to be drained into the floodway. The only practicable method for redeeming this tract without pumping is by building a levee all the way around it, leading the drainage water from without into an outlet ditch outside the levees, and then carrying the water of the inclosed area under the ditch and levee along the state line by means of an underground conduit into the ditch outside the Big Lake reservoir, where it will have a free outlet. The latter ditch is planned to be of sufficient size to serve that purpose. All the remaining area east of the floodway in Missouri will be diverted into the ditch along the state line, through which it will flow into the Big Lake floodway.

The ditch along the state line west of the floodway will carry water from the north into either the Little River or the St. Francis floodway, and will to a considerable extent relieve the conditions now existing along the state line in Missouri. These ditches are not planned to be of sufficient size to furnish complete outlets for Missouri water, and will require enlargement by the interests in Missouri. It is planned on this project to make them of such size as to give partial relief to Missouri land under present conditions, and to insure against any damage resulting to that land as a result of the levees built on the south side of these ditches.

The water in the St. Francis channel in Missouri will not be raised to any marked extent by the construction of the levees along the St. Francis in Arkansas. In order to complete the drainage of area No. 5, on the map above mentioned, it will be necessary to levee the St. Francis River in Missouri. It will be necessary also to carry this

---

[a] An. Rpt. War Dept., 1904, Vol. 5, p. 411.

levee south and inside the leveed channel in Arkansas, so that two levees and a channel between them will be on the east side of the upper St. Francis channel in Arkansas, to carry the drainage water from the area No. 5, above mentioned. This channel inside the leveed channel of the St. Francis and between the two levees should be made of sufficient size to give the water a very flat surface slope, and should be carried downstream to such a distance that the backwater from the main reservoir channel will not cause it to overflow in area No. 5. The area in Green County, Ark., directly west across the St. Francis, may be improved in the same way.

With these provisions no damage will result to Missouri from the construction of the system, but on the other hand the land in that State will be considerably benefited.

ADVANTAGES OF A LARGE DISTRICT.

In nearly every region where drainage is undertaken large sums of money are spent in ill-considered efforts before the necessity for a thoroughly efficient, comprehensive, and well-devised plan is realized. In some regions work of a temporary character later gives place to well-devised and efficiently executed plans; while in other cases, as is true of the English fens, large districts which could have been thoroughly and economically drained by proper plans are improved by haphazard efforts until the conflicting plans have been carried to a point where it is practically impossible to reconcile them to a well-considered system. The English fens, after having been taxed more than their value for haphazard drainage improvements, are now but partially reclaimed, and have a market value of perhaps $30 to $50 per acre for agricultural purposes. Just across the English Channel, the Holland lowlands, drained by a systematic and centralized plan, have a value for agricultural purposes of hundreds of dollars an acre, and not only supply the home demand for truck products, but also produce large quantities for export to the United States. It remains for the people of the district to decide which course will be pursued in the upper St. Francis Valley. It is possible for several parts of the district to be partially relieved by the execution of haphazard drainage work, at the cost of greater difficulty and increased expense for the final improvement. But the reclamation of the St. Francis Valley is a difficult problem, perhaps as difficult as that of any drainage project in the Mississippi Valley, and until this fact is realized and is given due weight in plans for improvements the best interests of the valley will not be served.

It is not necessary, in following a plan, for all of the work to be done at once; but, a proper system having been adopted, construction can be carried on year after year as demand arises, the final result being an efficient system. This result can be secured best by an organization having charge of the entire district.

ESTIMATE OF PROFITS.

In estimating profits from the execution of the proposed work, separate consideration may be given to agricultural lands, timber lands, lands held for investment and speculation, railroads, and towns and cities.

The profit of drainage to owners of agricultural lands varies with the conditions of the land before drainage, the thoroughness of drainage, the fertility of the soil, and the access to markets. Not more than 5 per cent of the land in this district has sufficient surface drainage, and much of that small fraction needs tiling. The greater part is worthless for crop production in its present condition, and this would receive practically its entire agricultural value from drainage. On a large part of the land now cultivated crops are frequently lost as a result of an excess of water, and yields are often but a fraction of what could be secured with thorough drainage. On other lands where crops are usually secured the yield could be largely increased by this improvement.

Lands held for investment and speculation will derive much of their value from this improvement. Probably between 5,000,000 and 10,000,000 acres of land are being reclaimed in the United States by drainage and irrigation. That region will be most attractive to intelligent investors which gives the surest evidence of thorough development in the immediate future. The experienced farmer with capital knows that his interest lies in paying a higher price for land which is capable of immediate development, and from which he can at once get returns on his investment, rather than in purchasing land the cultivation of which may be unprofitable for many years to come.

In this regard it is pertinent to inquire whether the interests of large holders of timber lands lie in developing the main drainage system now or in delaying it until practically all the timber is removed. If the main drainage system is carried through at this time the lateral drains will be constructed as fast as they are needed. Very many tracts will at once be improved and made into productive farms, furnishing an object lesson of the remarkable productiveness of the soil. Roads, homes, and schoolhouses will follow, with the result that as the timber lands are cut over they can at once be sold to persons from Illinois, Indiana, and Iowa who are willing to pay good prices for productive land in communities well on the way to industrial development. If, on the other hand, drainage is postponed until the timber is largely removed, agricultural development will begin in a country without roads, bridges, schools, or other improvements, and without the high reputation over the country for productiveness which will follow the thorough development of a

part of the area. This development, too, will take place in competition with that of millions of acres of other land throughout the country where a progressive policy is being pursued, where development will be well advanced, and where settlers on productive farms are acting as potent publicity agents. A few years' precedence in development, when many large areas over the country are being reclaimed, may have an important effect upon real-estate values.

Every town and city in the district obviously will be benefited by the agricultural development. The district comprises about 20 per cent of the territory which is most directly tributary to Memphis, and its development will result in a corresponding increase in the business of that city. Jonesboro, on the west, will also be largely benefited, as it has excellent railroad facilities and is more directly in communication with about half the district than is Memphis.

ADMINISTRATION.

ORGANIZATION.

The two methods by which the proposed district may be organized are: First, by working under the general drainage law of the State; and, second, by the organization of a drainage district by special act of the legislature covering the territory in question. The advantage of the first method is that it permits of organization at any time, even though a special law is passed at some future date to cover this special district. The advantage of finally working under a special act of the legislature is that it is difficult in a general law to make provisions for a district of the size and importance of this one. Moreover, in most instances a district is improved at one operation, whereas in this case it may be desirable to organize a district to have control over the area as a whole, allowing drainage improvements to be carried forward as demand may develop, but requiring all work to conform to a plan which will finally result in a well-ordered and systematic improvement.

FURTHER SURVEYS AND PLANS.

The surveys made and the plan here presented have as their object an outline of a general system of drainage which should be adopted for the entire region. But the plan is only a general one and before it is carried into effect complete surveys of the district should be made. Many changes in the locations of lateral ditches will be necessary, especially along the east and west margins of the district, where the preliminary surveys were not completed. Such detailed surveys should include a careful examination of the run-off of existing ditches, and certain stream gaugings as mentioned elsewhere.

As has been stated, run-off conditions in the district will be changed so entirely by the construction of the proposed system that the future run-off can not be judged by any gaugings made at present. However, in making further surveys, gaugings should be made at the following points: Where the St. Francis River leaves the hills a continuous gauge record extending over a severe storm period, and properly rated, would indicate to a degree the run-off which will occur in the future at this point; the St. Francis River should be gauged at the outlet of Big Bay, slope measurements being taken at the same time, for the purpose of determining the discharge of the lower river at any given stage; similar data concerning the St. Francis at Marked Tree and the Tyronza River in Cross County would be of value. Few other gaugings would be very useful in making detailed plans for the work.

ACQUIRING RIGHT OF WAY.

The district should absolutely own and control all the right of way of the ditch. In this case the fishing privileges on St. Francis reservoir and the possibilities of power development at the end of the floodway system are very important assets and should not be disposed of.

POLICY.

The success of an undertaking of this size depends very largely upon its being carried out by a conservative, well-organized, and efficient business system. If political considerations are allowed to have weight in the organization and operation of the district, the people of the territory will pay for that course in increased taxes and decreased benefits. The reclamation of the St. Francis Valley is one of the most difficult engineering problems of the Mississippi Valley, and unless handled in an intelligent and thoroughgoing manner the most successful results will not be secured.

The proper policy to be pursued in the drainage of this district can be embodied in two general statements:

(1) The improvement of the entire district should be carried out under a single definite plan and in such a manner that when fully completed the economical and complete reclamation of the entire district will be accomplished.

(2) While the entire work should conform to a single well-devised plan, the drainage of separate parts of the district should not be delayed unnecessarily because other parts are not prepared to undertake reclamation. It is possible to do a large amount of work in the outlying parts of the district in a way that will bring immediate relief, and will, at the same time, fit into the general system.

The construction of the floodway system would give such general relief that over large parts of the district no further improvement

would be found necessary for years to come. As the demand for thorough drainage increases, the lateral drains could then be constructed one by one as they should become necessary, and in substantial accordance with a complete plan. So far as lumbering operations are concerned, no other work aside from the construction of the floodway system and the improvement of Tyronza River and the Right-Hand Chute of Little River will probably ever be needed in the main body of the district. Except in the outlying portions, endeavors to drain before the floodway system is constructed must end in partial or complete failure. It is the backbone of the whole drainage system, and the policy of the district should include its construction in the near future. The construction of the Little River floodway, with ditches along the state line, at a cost of less than $1,000,000, would relieve two-thirds of the district of all danger of overflow.

FUTURE PROBLEMS.

COST OF MAINTENANCE AND REPAIR.

The channels of the lateral ditch system are planned of such size that they probably will not need extensive cleaning or repair for several years, but all drainage channels in this region will require repair eventually if they are to maintain efficiency. The cost of maintenance will be far less in a large district properly organized than in numerous small districts where the number of officials and the provisions for work must be multiplied. All the channels of this district are planned of such size that they will not need extensive repair for five or ten years.

The levees, when once properly seeded to grass and fenced for pasture, can be maintained at a very low cost. The chief engineer of the Yazoo levee district on the Mississippi estimates that on the completed levee system of that district the income from hay and pasturage on the levees and right of way will pay the cost of maintenance. The maintenance of a clean channel between the levees of the floodway is one of the most important questions in relation to the adoption of that plan of improvement. Two general plans are suggested which might be adopted to secure better conditions. The first is to mow the channel each year wherever weeds have begun to grow, using a mowing machine on a motor boat, such as is used in cleaning rushes from the beds of northern lakes. The cost of keeping the channel in condition by this method should not exceed 50 cents an acre, or $6,000 a year. The other method consists in building low timber dams, about 5 feet high, across the floodways at such intervals that the deepest water in the floodway would be 5 feet and the shallowest about 2 feet deep during lowest water.

The extreme flow anticipated in the floodway is a depth of 12 feet, with a velocity of 2½ feet per second. In time of such a flow the water over the 5-foot dam would rise 4 or 5 inches higher than it would be if there were no dam across the floodway, according to Merriman's formula for flow over submerged dams. The integrity of the levee system would in no wise be endangered by the proposed dams. If built of wood and backed with earth the three required for the St. Francis floodway would cost probably less than $10,000, and the two required for the Big Lake floodway less than $5,000, making $15,000 for the cost of such dams for the entire floodway system. This expenditure would maintain the channels in good condition at an annual cost for maintenance of not more than $3,000. In addition, these dams would become a part of a transportation system, and would be useful in connection with a gravity supply of water for rice irrigation.

In the case of Tyronza River and the right-hand chute of Little River, where the channel is planned to be deeper than that now existing, sand bars may form in some places and may require repeated attention. While it is not desirable to construct channels as deep as these which are planned, no other course seemed to be open, and the question of maintenance will not be especially serious, as the deeper cuts are short.

High water in the floodway will occur so seldom that protection against waves seems unnecessary, except perhaps by allowing a strip of willows to grow to a height of 8 feet along the inside of the levee line. Within the St. Francis reservoir the timber should be allowed to stand inside the levees, and this will prevent damage from waves for years, until the trees decay and fall down. Other provision may then be found necessary in a few places.

Considered as a whole, the annual expense for maintenance of the completed district, beginning after some years' deterioration, should not exceed 2 to 4 per cent of the entire first cost of the work.

TILE DRAINAGE.

The completion of the drainage system as planned would result in giving nearly every acre in the district as thorough drainage as the best parts along the river have at present. A part of the district has a light sandy soil and probably never will require any further drainage for its complete reclamation. But as in the States farther north it is found that production on heavy soils can be much improved even where these have good surface drainage, so it probably will occur that in this district landowners in time will be satisfied with nothing less than thorough tile drainage for the heavier soils. The greater part of the land in the district now in cultivation would be greatly benefited by tiling.

In planning a complete drainage system the probable necessity for tile drainage in the future should be clearly recognized and provided for. It is believed that every ditch planned in this system, with the possible exception of two or three in lake beds, is of sufficient depth to furnish complete outlets for such systems.

THE CONSERVATION OF SOIL MOISTURE.

Perfect drainage consists in removing from the soil the excess of moisture which it may contain and in retaining sufficient moisture for the supply of growing crops. Conditions in the proposed district are especially favorable for accomplishing this purpose. The lateral ditches are planned of such size that flood waters will be removed rapidly, but of moderate depth, from 7 to 9 feet. With a few unavoidable exceptions, no provisions are made in the entire plan for ditches more than 10 feet deep. It will therefore not be difficult to regulate the depth of flow and consequently the depth of ground water, if this shall prove desirable, by the use of low dams across the ditches during dry seasons. It is quite probable that this soil will hold sufficient water, even during dry seasons, to supply ordinary crops, and that the regulation of the ground water level will not be necessary in many instances. The proper depth below the surface of the ground water for growing ordinary crops in this soil is $1\frac{1}{2}$ to 3 feet, while alfalfa grows best if the ground water remains at a uniform depth of several feet. In the reclaimed land of Holland effort is made to keep the ground water at a depth of 12 to 15 inches for grass and at a depth of 20 to 30 inches for grain crops. Sandy soils in Holland require a high ground water level, while clay soils will retain enough moisture to grow crops even though thoroughly drained. The sandy soils of the Sikeston Ridge in southeastern Missouri seem not to suffer from drought, even when the water table is several feet from the surface.

BURROWING ANIMALS.

Since the preparation of the preliminary report a careful study has been made of the extent to which muskrats infest and damage levees in this region. A part of the levees provided for in this plan will have water about their bases for the entire year, and so will be subject more to damage from this source than levees located on higher ground. However, investigation has led to the conclusion that damage due to the burrowing of these animals will be far less than would be the case in some other parts of the country, and it was decided that no considerable expense need be incurred to prevent such damage. Should any part of the levee become infested with muskrats the situation can be handled locally at a small cost

UNEXPECTED DIFFICULTIES.

In a project of this size many local difficulties and unexpected problems are sure to arise in the detailed planning and in the prosecution of the work. The organization of the project should give sufficient freedom of action for handling such conditions as may arise, and the detailed survey should be of sufficient thoroughness to make them evident.

UNIT PRICES OF ESTIMATES.

For all lateral ditches excavation is estimated at 8 cents per yard, including the cost of clearing the right of way.

The earth used for building levees should be measured in excavation, and no shrinkage need be provided for, as the levees are planned to be of sufficient size after shrinkage has occurred. This provision will reduce the unit cost of work to the contractor more than 1 cent per yard as compared with the usual methods of calculation. No grubbing of the levee base will be required, and the muck ditch, to be constructed by a dredge, will be paid for in addition to the fill. An estimate of $150 an acre is made for grubbing and clearing the ditch section, which will serve as a borrow pit for earth, and $20 an acre for clearing the levee base and berm. It is anticipated that all levee construction will be by machinery. Levees under 12 feet in height are estimated to cost 9 cents per yard and those over 12 feet 10 cents per yard for fill. These prices correspond to 12 and 14 cents per yard for levee work as ordinarily calculated, including shrinkage, muck ditches, clearing, borrow pits, dressing slopes, and similar items.

Excavation in the channels of Tyronza River and the Right-Hand Chute of Little River is estimated at 9 cents per yard, including the cost of clearing right of way.

Clearing right of way for the floodways and levees is estimated at $20 per acre, and grubbing the ditch sections along the levees, so that hydraulic dredges or drag-scraper machines may operate successfully, at $150 per acre.

Nearly all ditches are 10 feet deep or less. The width of right of way is estimated to be three times the top width of the ditch, plus the width of berm, and all right of way on the entire project except that in old channels or meandered lake beds is estimated to cost $20 per acre. Along Tyronza River and Right-Hand Chute a right of way 100 feet wide on each side of the channel is specified.

It is believed that every construction included in this plan is abundantly sufficient for its purpose, and that where changes are

made as the result of a more complete study of the situation they will be in reductions of dimensions. This is especially true in relation to the floodways. A large factor of safety has been used on every phase of the work except in estimating the unit cost of earthwork. The cost of the work to the district is estimated at twice the estimated cost to the contractor if the work is done in a systematic manner and by the use of modern machinery. The estimates represent about the lowest price at which similar work is being contracted for; but it is believed that with a business management and the sale of the work to the best advantage to contractors able properly to equip themselves, the prices here given need not be exceeded. It is seldom that so favorable a piece of work from the contractors' standpoint is constructed.

Mr. Otto Kochtitzky, of Cape Girardeau, Mo., chief engineer of the Little River drainage district and a large drainage contractor, was asked to give his opinion of the probable cost of this work, and stated his opinion as follows:

Where 15 miles or more of ditch can be constructed by once installing the machine, the cost should be within the following figures:

Ditch 12 feet bottom, 8 feet deep, 8 cents per cubic yard.
Ditch 20 feet bottom, 8 feet deep, 6 cents per cubic yard.
Ditch 40 feet bottom, 10 feet deep, 5½ cents per cubic yard.
Ditch 60 feet bottom, 10 feet deep, 6 cents per cubic yard.
Ditch 80 feet bottom, 10 feet deep, 6½ cents per cubic yard.

For constructing the levee by use of the scraper-bucket machine for the smaller levee, 12 feet high, the cost will be about 8½ cents per yard above cost of grubbing, and for the larger levee I presume it will run to about 10 cents per yard besides cost of grubbing. The muck ditches 20 feet wide will cost about $1,200 per mile.

My estimate for the dredge ditches is based upon three years' experience in this locality as a contractor and eleven years' employment in this locality as an engineer in charge of such work. The levee construction by scraper-bucket machinery is estimated from my observation of the use of those machines, but with which I have had no experience as contractor and the prices at which similar work has been lately contracted.

I have no doubt the cost of this work can be reduced by the use of a suction dredge in connection with the scraper-bucket machine. The scraper-bucket machine will possibly handle earth at about the same price as dipper dredges wherever dipper dredges can reach the dumping distance, but where the scraper bucket is required to pick up the material on one side and swing the full half circle in order to deposit at proper distance from excavation point the cost is somewhat increased, probably 25 per cent above the cost of the shorter distance.

On being asked to define more definitely his meaning of the term "cost," he replied as follows:

The prices given were intended as the lowest reasonable expectation for contractor's prices. I would be willing to undertake that work at this time at those prices if pay were absolutely assured in cash.

ESTIMATE OF COST.

FLOODWAY AND RESERVOIR SYSTEM.

Upper St. Francis floodway and reservoir:		
Right of way (surveyed land), 7,190 acres, at $20 per acre.	$143, 800	
Clearing right of way, 4,600 acres, at $20 per acre	92, 000	
Grubbing and clearing 700 acres, at $150 per acre	105, 000	
Levees, 2,184,200 cubic yards, at 9 cents per yard	196, 578	
Levees, 3,092,200 cubic yards, at 10 cents per yard	309, 220	
Muck ditch, 29.3 miles, at $2,503.10 per mile (8 cents per yard)	73, 341	
Muck ditch, 22.6 miles, at $2,002.16 per mile (8 cents per yard)	45, 249	
Railroad bridge adjustment at Lake City	5, 000	
Highway bridge adjustment at Lake City	2, 500	
		$972, 688
St. Francis floodway:		
Right of way, 9,880 acres, at $20 per acre	197, 600	
Clearing right of way, 9,050 acres, at $20 per acre	181, 000	
Grubbing and clearing 830 acres, at $150 per acre	124, 500	
Levees, 9,041,800 cubic yards, at 10 cents per yard	904, 180	
Muck ditch, 49.4 miles, at $2,503.10 per mile (8 cents per yard)	123, 653	
Passing through Frisco Railroad bridge	2, 000	
One highway bridge	15, 500	
One highway bridge	13, 200	
		1, 561, 633
Upper Little River floodway:		
Right of way (surveyed land), 140 acres, at $20 per acre	2, 800	
Clearing right of way, 2,850 acres, at $20 per acre	57, 000	
Grubbing and clearing 110 acres, at $150 per acre	16, 500	
Levees, 315,100 cubic yards, at 9 cents per yard	28, 359	
Levees, 660,300 cubic yards, at 10 cents per yard	66, 030	
Muck ditch (on east side), 6 miles, at $2,002.16 per mile (8 cents per yard)	12, 013	
		182, 702
Lower Little River floodway:		
Right of way, 5,825 acres, at $20 per acre	116, 500	
Clearing right of way, 5,400 acres, at $20 per acre	108, 000	
Grubbing and clearing 425 acres, at $150 per acre	63, 750	
Levees, 1,537,400 cubic yards, at 9 cents per yard	138, 366	
Levees, 2,619,400 cubic yards, at 10 cents per yard	261, 940	
Muck ditch, 28 miles, at $2,002.16 per mile (8 cents per yard)	56, 060	
Muck ditch, 13.5 miles, at $2,503.10 per mile (8 cents per yard)	33, 792	
One culvert (under lower end of floodway)	40, 000	
One highway bridge	11, 000	
Paragould and Memphis Railroad bridge	42, 000	
Jonesboro, Lake City and Eastern Railway bridge	35, 000	
		906, 408
Total cost of floodway and reservoir system		3, 623, 431

DITCH SYSTEMS.

System No. 1.—West of St. Francis floodway and reservoir (ditches Nos. 1 to 38, inclusive):		
Miles of ditch (not including 54.7 miles along floodway and reservoir), 264.1.		
Right of way, 3,400 acres, at $20 per acre	$68,000	
Excavation (this includes excavation along floodway and reservoir not necessary for levee construction), 13,019,000 cubic yards, at 8 cents per yard	1,041,520	
		$1,109,520
System No. 2.—North of Little River floodway, except drainage discharged through culvert (ditches Nos. 39 to 69, inclusive):		
Miles of ditch (not including 45.5 miles along floodway), 142.7.		
Right of way, 2,300 acres, at $20 per acre	46,000	
Excavation (this includes excavation along floodways not necessary for levee construction), 4,069,200 cubic yards, at 8 cents per yard	325,536	
		371,536
System No. 3.—Mississippi County drainage into upper Little River floodway (ditches Nos. 70 to 75, inclusive):		
Miles of ditch, 51.6.		
Right of way, 820 acres, at $20 per acre	16,400	
Excavation, 2,117,100 cubic yards, at 8 cents per yard	169,368	
		185,768
System No. 4.—Between Tyronza drainage area and floodways (ditches Nos. 76 to 142, inclusive). (This estimate does not include district No. 1, now under construction in Poinsett County):		
Miles of ditch (not including 60.8 miles along floodways), 276.1.		
Right of way, 2,630 acres, at $20 per acre	52,600	
Excavation (this includes excavation along floodways not necessary for levee construction)—		
8,786,300 cubic yards, at 8 cents per yard	702,904	
2,280,300 cubic yards, at 9 cents per yard	205,227	
		960,731
System No. 5.—Tyronza River drainage area, ditches Nos. 143 to 185, inclusive (this does not include district No. 8, in Mississippi County):		
Miles of ditch, 303.8.		
Right of way, 4,000 acres, at $20 per acre	80,000	
Excavation, 9,421,900 cubic yards, at 8 cents per yard	753,752	
Excavation, 1,658,500 cubic yards, at 9 cents per yard	149,265	
		983,017
Total cost of ditch systems		3,610,572

Total miles of ditch (not including 161 miles along floodways and reservoir), 1,038.3.

SUMMARY.

Floodway and reservoir system	$3,623,431	
Ditch systems	3,610,572	
		$7,234,003
Engineering, legal, and contingent expenses (5 per cent)		361,700
Total cost		7,595,703
		Acres.
Approximate area of district		1,040,000
The above includes district No. 1, of Poinsett County; district No. 8, of Mississippi County; land occupied by floodways and reservoirs; and land on the borders of the district not affected by this improvement, aggregating about		200,000
		840,000

Approximate average cost per acre, $9.04.

ACKNOWLEDGMENTS.

In addition to the field work, every other source of information was carefully investigated to secure applicable existing data. The few useful data found were only used after being carefully checked and found correct. The information was supplied as follows and acknowledgments are due to the persons and companies named for the assistance which they rendered: The St. Louis and San Francisco Railroad Company, a profile of its line through the district; the Mississippi River Commission, data of three level lines which had been run across the valley under its direction; the St. Francis Levee Board, a list of bench marks along the Mississippi River and field notes of a survey of three sections in the interior of the district; the War Department office at Little Rock, a profile of the water surface in the St. Francis River; the Kansas City Improvement Company, data of their survey of the south end of St. Francis Lake; Mr. C. B. Bailey, of Wynne, Ark., field notes of a system of cross sections of Big Bay in Poinsett County and profiles of two other ditch systems; Mr. W. E. Ayres, who loaned his map of district No. 8 in Mississippi County; and Moore & McFerren Company, profile of a proposed railroad line. So far as is known no valuable data concerning the physical features of the valley were overlooked.

REPORT OF THE BOARD OF CONSULTING ENGINEERS ON THE REPORT ON THE ST. FRANCIS VALLEY DRAINAGE PROJECT.

Mr. C. G. Elliott,

Chief of Drainage Investigations.

Sir: We have read carefully the report on the St. Francis Valley drainage project prepared under your direction by Mr. Arthur E. Morgan, assisted by Mr. O. G. Baxter. In connection with this report we have studied the maps, profiles, and other drawings pertaining to the work, and we present hereinafter our conclusions and recommendations based upon our studies as before mentioned.

The scope of the project as it presents itself to our minds is comprehensive and well considered. Local drainage projects covering only portions of this district are sure to result in failure and a large and useless expenditure and often in damage to related sections unless the plans are made to conform strictly to adequately developed plans covering the entire district affected. The assumptions for run-off, both from the flat lands and from the hill country, are in accordance with what we conceive to be safe and sane practice. We have made such computations on the capacity of the floodways as to satisfy ourselves that they are of sufficient capacity to care for the greatest run-off that a tenable theory of rainfall would lead us to anticipate. We have not computed all of the lateral ditches tributary to these floodways, but have taken a number of them here and there throughout the system and computed them as checks upon the methods used and their execution, with satisfactory results. We find that the methods of levee construction and the dimensions of the levee are in accordance with good practice, better practice, in fact, than is commonly met with in this character of work.

Questions have arisen in our minds as to the necessity of having the floodways as wide as they are in some places, but the data are not at hand to give us a basis for seriously questioning the propriety of the layout as it is presented to us.

Taking up the St. Francis reservoir, we ask ourselves if that reservoir area can not be safely reduced and valuable lands reclaimed, but the data are not now available for determining whether an attempt to save lands within that reservoir area would not result in expenditures exceeding the value of the lands to be reclaimed. We therefore suggest that these questions be left for later decision after further data have been obtained upon which to predicate a valid conclusion.

We recognize the practicability of the suggested development of water power and believe that such development will have a value greatly in excess of the cost of development, and, further, that such development is entirely consistent with the working out of the drainage project upon its most efficient lines.

We believe that the channels created for drainage will also serve as channels for shallow-draft boats that will engage in transporting to natural markets the agricultural products of this reclaimed land, and that as waterways they will have a real value in addition to that for which they were primarily designed.

The methods of constructing these ditches and floodways, as recommended, are well considered and up-to-date. The unit prices used in computing the cost of the work are based upon experience in other similar work, and they seem to us to be justified by costs shown on other work.

It must be recognized that the surveys for this work are not in such detail as to enable an estimator to feel sure in all cases that fuller information will not change his results, but it seems to us that the effort has been to show maximum quantities in the estimate submitted, and we anticipate that the actual quantities involved in this construction will fall below those now reported, with a corresponding reduction in cost.

Perhaps the most serious question in connection with the proposed plans is that of maintenance. Proper maintenance of the levees upon whose condition the safety of the entire region will depend is, of course, of vital importance. In addition, the great floodways must be kept clear of obstructions, especially vegetation, at all times. For the floodways we prefer a system, such as flooding by submerged dams, which will prevent growth of vegetation. An effective, permanent drainage district organization must be provided for maintenance, supplied with proper funds for constant work.

Respectfully submitted.

(Signed) Isham Randolph.
A. Marston.
S. M. Woodward.

Chicago, Ill., *July 6, 1910.*
230–1

○